FROM STUDENTS TO RESEARCHERS: THE EDUCATION OF PHYSICS GRADUATE STUDENTS

DISSERTATION

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

By

Yuhfen Lin, B.Sc., M.Sc.

* * * * *

The Ohio State University

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Dissertation Committee:
Professor Gordon J. Aubrecht II, Adviser
Professor Bruce R. Patton
Professor Mohit Randeria
Professor Alan Van Heuvelen

Approved by

Adviser
Graduate Program in Physics
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ABSTRACT

This dissertation aims to make two research contributions: 1) In physics education research, this work aims to advance our understanding of physics student learning at the graduate level. This work attempts to better understand how physics researchers and teachers are produced, and what factors support or encourage the process of becoming a researcher and a teacher. 2) In cognitive science research in the domain of expert/novice differences, researchers are interested in defining and understanding what expertise is. This work aims to provide some insight into some of the components of expertise that go into becoming a competent expert researcher in the domain of physics. This in turn may contribute to our general understanding of expertise across multiple domains.

Physics graduate students learn in their classes as students, teach as teaching assistants, and do research with research group as apprentices. They are expected to transition from students to independent researchers and teachers. The three activities of learning, teaching, and research appear to be very different and demand very different skill-sets. In reality, these activities are interrelated and have subtle effects on each other.

Understanding how students transition from students to researchers and teachers is important both to PER and physics in general. In physics, an understanding of how physics students become researchers may help us to keep on training physicists
who will further advance our understanding of physics. In PER, an understanding of how graduate students learn to teach will help us to train better physics teachers for the future.

In this dissertation, I examine physics graduate students’ approaches to teaching, learning, and research through semi-structured interviews. The collected data is interpreted and analyzed through a framework that focuses on students’ epistemological beliefs and locus of authority. The data show how students’ beliefs about knowledge interact with their learning, teaching, and research activities. In many cases, their perception of the learning, teaching, or research environment influences their choice of learning, teaching, or research approach. Physics graduate students learn “the language of physics” from the core courses, but don’t learn many transferable research skills from taking courses. Constrained by the teaching environment, many graduate students are not motivated to teach as teaching assistants. Some finishing graduate students have clearly become confident and able researchers, while others remain dependent on their advisors for even the simplest direction. The data also show that it is possible for a single graduate student to hold very distinct beliefs about learning and teaching between classroom and research settings. It is possible for a well-motivated graduate student to take unfavorable approach toward learning when the environment does not support learning for deep understanding.

This dissertation attempts to distill out aspects of success in the graduate program and identify features of positive experiences that help graduate students to transition from students to competent and confident researchers. The data suggest that having graduate students treated as legitimate participants is the vital element for them to build their confidence as researchers and teachers.
This dissertation is dedicated to all the physics graduate students
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VITA

24 February, 1975 ......................... Born - Taipei, Taiwan

1997 ......................................... B.Sc. Physics, National Taiwan University, Taiwan

1999 ......................................... M.Sc. Physics, National Taiwan University, Taiwan

2004 ......................................... M.Sc. Physics, The Ohio State University

2000 - 2007 ................................. Graduate Teaching Assistant in Physics, The Ohio State University.

PUBLICATIONS

Research Publications


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CHAPTER 1

INTRODUCTION

The future of physics education depends on the future physics faculty. The quality and sustainability of reforms and improvements in undergraduate physics education depend on informed physics faculty who have a deep understanding of teaching [1]. Future physics development also depends on the future physics faculty. The quality of physics research depends on physicists who have developed expertise in doing physics research. Most importantly, future physics faculty come from today’s physics graduate students. Thus, the quality of future physics faculty depends on the quality of the education of physics graduate students. A careful examination of physics graduate student education will be the overarching goal of this dissertation.

Currently, the majority of physics education researchers still focus their research on introductory level physics or teacher education [2]. A small portion of physics education researchers have started to pay attention to the upper-level undergraduate physics courses. Even fewer researchers are looking at graduate-level education. Right now, there are several research programs working on improving the teaching abilities of the current and future physics faculty. For example: the Preparing Future Physicists (PFP) program was designed to prepare physics graduate students to be
future educators [3]. Henderson and Dancy used qualitative methodologies to examine the mechanisms that affect physics faculty’s teaching approaches [1]. There are some more research projects working on teaching assistant (TA) development [4]. All the graduate level physics education research has focused only on the teaching aspect of physics graduate students’ development. No one has systematically looked at the physics graduate program as a whole and thought about how and what students are learning in that program.

Looking at existing physics education research, the way researchers study the effectiveness of the introductory physics curriculum is to study how well students learn in introductory physics courses. In order to study the physics graduate program the same way, we should look at how well physics graduate students learn in the physics graduate program. Unfortunately, unlike introductory physics courses, there are no existing standardized tests for graduate level physics. Even before we try to test the graduate students to see if they’ve learned what we want them to learn, we need to decide what it is that graduate students should be learning in the graduate program. We need to ask ourselves if a standardized test would be able to measure what we want physics graduate students to learn [5, 6].

The future physicists come from the physics graduate students of today. Before we examine the successfulness of the physics graduate program, we need to create a framework for studying it. In this dissertation I will propose a framework, based on a systematic study of education, psychology, and cognitive science literature. This framework will be used to conduct an observational study on physics graduate student learning in the physics graduate program. This study will help us better understand
the function of the physics graduate program and the processes by which physics graduate students transition from students into researchers and teachers.

In this dissertation, I will first consider what the goals of the physics graduate program are. In considering the goals of the program, I will ask what we want graduate students to achieve in the program. Secondly, I will look at what graduate students do in the graduate program. Graduate students are required or suggested to engage in a number of activities throughout their graduate career in order to learn the research and teaching skills they need in the future. Thirdly, with the goals that graduate students need to achieve in mind, I will take an in-depth look at the graduate students, attempting to understand what it is that they learn from the graduate program and how they learn it. To understand this I will introduce several theoretical viewpoints and apply them to my analysis of graduate student learning. In this chapter I will give a broad overview of the goals of the physics graduate program, the types of activities that graduate students engage in, and some theoretical perspectives on how learning takes place at this higher level.

1.1 The Goals of the Physics Graduate Program

Physics graduate students are the source from which future physicists are drawn. There are many possible reasons why students choose to pursue a career as a physics graduate student. Some possibilities are: a desire for knowledge, a desire to teach at a college level, a desire to learn higher order problem-solving skills that can be transferred to careers in industry or government labs, and/or a desire to engage in research and become an academic. What is certain is that all physics graduate students are expected to learn some physics and engage in original research in physics
in order to be awarded a Ph.D. One way to examine the goals of the graduate program is to look at what a physics professor does in her/his job.

An average physics professor is required to teach physics courses, lead or contribute to a research group conducting research, advise graduate students, and provide service to the research community. That means a professor should be able to teach, to do research, and to be a mentor [7].

Alternatively we can ask: What are the goals of the physics graduate program? What is the physics graduate program trying to prepare physics graduate students for? The OSU physics department has the goals of the program on their web site as follows:

We have designed the graduate program in physics to give you a solid background in the fundamentals, an understanding of the major fields of current research, and an opportunity for in-depth investigations. [8]

These goals are quite common among the physics graduate programs. Most physics graduate programs include the following two goals describing what students should have achieved during their physics graduate study:

1. Students need to have a baseline knowledge of physics.
2. Students need to learn how to conduct research.

Most physics graduate programs have a similar structure [9] to help students achieve the above goals. In the first few years of their graduate careers, physics graduate students are required (or recommended) to take a set of core courses to prepare them to pass a qualifier exam. In the case of some physics departments, students are required to pass those core courses with a set GPA in lieu of the qualifier.
After the core courses, students take a few more advanced courses as an introduction to their chosen research sub-field. Simultaneously, students start to conduct research with their chosen research group [9].

While working with the research group, students are expected to acquire the skills they need to conduct research in their research field through working on ongoing or new research projects. Before they complete their study, students are expected to conduct an original research project that they will defend before their thesis defense committee. Once this research is approved, the Ph.D. degree is awarded.

If we realize that a Ph.D. cannot be awarded without a research component, it is reasonable to say that the most important goal of the graduate program is to prepare graduate students for future research activities. It is therefore necessary to ask: How does each of the program activities that students engage in during their graduate career contribute to the goal of turning them into researchers? This will be one of the primary research questions of this dissertation. While turning students into researchers is the main focus of this dissertation (as may be deduced from the title) I will also consider how graduate students develop as teachers in the graduate program since this is one of the major activities in which physics faculty are expected to engage.

1.1.1 Learning as Acquiring Knowledge

It is a safe assumption that the reason students need to have some baseline physics knowledge is because they need some of that knowledge when they conduct research. Since most students take core courses before they decide which field they will conduct their research in, logically, the core courses should prepare students for all the possible
sub-fields of physics. This poses a problem. There is simply not enough time and too much physics knowledge to prepare all students adequately for all possible physics subfields. In addition, much of the physics that is relevant to one sub-field may be irrelevant to another.

It is clear that much of the knowledge that students will need to acquire to become researchers will be learned “on the job,” rather than in the core courses or even the advanced courses. Therefore another possible goal for the core courses is to prepare students to learn in the future. Instead of trying to teach all the possible physics knowledge students may not need in the future, perhaps a graduate program should help students develop learning skills so they can learn anything they need in the future when they need it. One of the core issues that has emerged from my research is that it may be necessary to reconsider the goals of the core courses in terms of the idea that students need to be able to transfer what they learn in the classroom to the new situations. This includes both the content that they have learned and the learning skills they have acquired.

1.1.2 Learning for Transfer and Preparation for Future Learning

Educators have valued transfer as the ultimate goal for school learning, since it is generally agreed that education can only be useful if students can transfer what they learned to situations outside of classroom [10].

Cognitive researchers have been studying the mechanisms of transfer for decades. The common approach to transfer is called direct application (DA). After the instruction of how to complete one task, the subjects are given a new task that requires them to apply what they just learned to a new situation. Researchers found that the
possibility that transfer occurs is strongly correlated to how similar the two tasks are in surface features. At the same time, often despite the effort of instruction, most subjects fail to transfer what they have learned to a novel but structurally similar situation [11].

Bransford and Schwartz have suggested a new way to approach transfer called preparation for future learning (PFL) [12, 13]. The idea is that rather than measure whether subjects can transfer their knowledge to a new situation, we should measure how well subjects can learn about a new situation. They consider that most traditional transfer experiments have taken place in sequestered environments where subjects are unable to demonstrate their ability to learn. Instead of using sequestered problem solving (SPS) tasks to measure the degree of transfer, they identified experiments in which subjects were given a chance to learn about the new situation in a resource-full rather than a resource-poor environment. They define the successfulness of transfer as measured by how well subjects can use the available resources to learn rather than how well subjects can demonstrate what they have learned.

To prepare physics graduate students for the future research and teaching, they need to have the abilities to acquire new knowledge as they need it in the future. They also need to be able to transfer what they have learned in the classroom into new situations they might encounter in the future. For both conditions, I am going to propose in this dissertation that graduate students should be prepared for future learning.

In this dissertation I will reconsider the physics graduate program through the lens of PFL. When students start doing research, what they are expected to perform is not to recall the facts or repeat the complex derivations that they have learned in
class. Doing research is not like taking a timed exam in which students are expected
to solve all the problems alone without any book or help. In the research environment,
researchers are expected to use all the resources they can find to learn new techniques
and develop new ideas in order to solve problems that have ill-defined or unknown
answers.

Another reason why it is important to examine the physics graduate program
from the PFL perspective is this: From AIP enrollments and degrees report [14],
slightly more than half of entering physics graduate students completed the Ph.D.
program, and about one quarter finished with a masters degree. Of those students
who completed their Ph.D., 63% took an academic job while 15% went into the private
sector and 20% work for government. In summary, a majority of starting physics
graduate students do not go on to become college physicists, yet we hope that they
have learned useful scientific abilities [15] in the graduate program, analytical and
problem-solving abilities that they can transfer to their job, no matter what field
they find themselves in.

In summary, I am going to suggest that the primary goal of the graduate program
should be to prepare graduate students for future learning. They should be able
to transfer the skills they learned in taking courses into doing research and teaching.
They should be able to transfer the skills they learned from working with one research
group to the new research problems they would be working on in the future. Even
if they decide that they are not going to stay in academia, it would be beneficial if
they were able to transfer some of the skills they have learned about learning physics
to whatever job they end up doing, and be able to learn the new skills they need for
their future work.
1.2 What do Physics Graduate Students do in Order to Achieve These Goals?

Physics graduate students spend an average of six years in the graduate program before they receive the Ph.D. degree [16]. There are three major components in their graduate study. They take courses as students. They teach as teaching assistants. They do research as research apprentices in a research group.

The goal of taking courses for graduate students is to gain physics background knowledge. Learning in the classroom setting has an advantage that the instructor has organized all the course materials and presents them in the order that would be most efficient for students to learn. Although physics education research has shown that students learn better in more interactive environments [17], since graduate students have been successful in their undergraduate study, I will show from my data that it is generally assumed (even by the graduate students themselves) that they will take active approach to learning even in the passive setting of a lecture-only course.

Graduate students teach as teaching assistants, not only for the financial support, but also to develop their teaching skills. Graduate students normally teach as a recitation or a laboratory TA with the course materials provided to them. They also receive some sort of training before they teach, but normally they are not given much freedom to decide how or what to teach [18].

Graduate students learn to do research in the research setting similar to traditional apprenticeship [19, 20]. They are encouraged to join the research group as early as possible. A lot of them even have had some research experience in the course of their undergraduate study. If we apply the model of apprenticeship to graduate
students learning to do research, we would expect to see the following features: Graduate students, working within a research group have a chance to see how researchers (professors, post-docs, and other graduate students) work on research. They start to participate in a small way in the research. Slowly, as they build up more research skills and gain more field-specific knowledge, they take on more responsibility for research projects. At the end, they are expected to take the leading role in their thesis research. From the data I’ve collected I have found some striking examples of students becoming competent and successful researchers in a research environment that shares many of the features of apprenticeship described in this paragraph.

Most importantly, the learning, teaching, and research components of graduate study may seem independent of one another. At the same time, I will suggest in this dissertation that there are some deep relationships connecting these three activities. Seeing these connections will allow us to better understand the intellectual development and changes that graduate students undergo in the physics graduate program.

1.2.1 Teaching and Learning

How are teaching and learning related to each other? Teaching requires that the learners (the students) learn while the teacher teaches. The act of teaching doesn’t exist when there is no student learning. Since the act of learning and teaching always occurs at the same time, I will consider that there are some fundamental connections between teaching and learning.

It is a common belief amongst education researchers that people normally teach the way they were taught [21], although there are few, if any scientific studies to back
up this hypothesis. For the case of physics graduate students, since most of physics courses are taught in the lecture format, it would not be surprising if most of them choose to teach in a traditional style [22, 23, 24]. This is especially true because they never experience any other alternative instruction as learners.

In a study of how PER reforms are implemented in physics departments, Dancy and Henderson [25] showed that regular physics instructors often choose to teach in a traditional way despite having PER-compatible teaching goals. Even if instructors try to adopt reformed practices, sometimes they miss a key element. For example, an instructor might encourage interactive discussions with the students, but the discussion may still be very teacher-centered such that the instructor leads the discussion and students' alternative ideas are not encouraged. If physics graduate students learn in their graduate courses via more PER influenced practices, they would have the chance to experience how learning happens in the more student-centered, interactive setting. As future instructors, graduate students would have a better chance to understand the reasons behind the PER approach and have exemplars to transfer into their own teaching practice.

1.2.2 Learning and Research

We presume that graduate students learn physics in the core courses to prepare for future research. At first glance, learning in class and doing research are two very different activities. If we examine this more closely, doing research is nothing more than learning in an unknown area. What researchers do is essentially to use the systematic methods of their research field to generate (for the researcher, it is the same as for a learner) new knowledge. What researchers do in doing research is not
much different from what learners do in learning [26]. Although physics knowledge may be already known to the lecturer delivering the lecture, that knowledge is largely unknown to the students. Active learning involves learners generating new understanding of the unknown. Although the methods of knowing may be different in the case of the graduate core courses, the activity should be fundamentally the same as research. Learning and doing research both involve making observations, coming up with new models, and evaluating the models with known knowledge [27]. Since graduate students have already spend substantial amount of time in school, we can assume they are “expert learners;” at the same time, they are just starting to build up their research skills, they are “novice researchers.” The research question that arises out of this is the following: How do graduate students pursue their learning in the courses compared to how they perceive doing research? Do students take a deep or surface approach in learning new knowledge? And how is their approach influenced by the context of learning? For example, do they behave differently in a classroom as opposed to a research setting?

1.2.3 How are Graduate Students Assessed and How do We Motivate Them to Learn?

From previous student motivational studies we have learned that when students are motivated to learn: they learn better, they retain the knowledge they learn longer, and they are more persistent in their learning (they do not quit easily when they fail) [28]. In the best situation, physics graduate students should be motivated intrinsically. That is, they are interested in learning physics and not dependent on the external forces such as tests and grades to drive them to study.
While graduate students should be self-motivated, this doesn’t mean we should abandon external motivation completely [29]. On the other hand, we should rethink the use of assessments as part of instruction [5, 6]. We need to assess for what we value and what we want students to learn [29]. Thus the learning goals of the graduate program should determine the types of assessments we apply. This goes back to direct application versus preparation for future learning [13]. If we want to prepare students to become researchers, and research is essentially learning in an unknown area, the best way to assess graduate students is by PFL-type assessments to measure their ability to transfer to the new situation.

How are graduate students currently assessed in the program in order to measure how well they have learned in each stage? There are three major examinations graduate students have to pass in the graduate program [9]. First, the qualifier is in a traditional assessment format, similar to the core courses, which generally adopt the same format of assessments. Candidacy exams (sometimes referred to as general exams) and the final thesis defense are both performance assessments, which means that students are tested in the situation similar to what they should perform in the real world. These two tests are both PFL tests in the manner Bransford and Schwartz envision. In contrast, both the tests that students take for core courses and the qualifier exam are not PFL tests. Except for rare circumstances, course and qualifier exams are conducted in a sequestered problem-solving format, which has been shown as an ineffective way of measuring PFL.

The assessment of how well graduate students teach generally relies on student evaluations completed by their undergraduate students. These evaluations measure
student satisfaction rather than student learning. First, graduate students are expected to teach with no basic understanding of learning theory or awareness of pedagogical content knowledge [30]. Then the assessment may not value the kind of teaching that promotes student learning. With no control over their teaching environment, there is very little room for graduate students to develop and practice their teaching skills as teaching assistants [18].

1.3 Transitioning from Students to Researchers and Teachers

During the time of graduate study, physics graduate students need to transition from students to researchers and teachers. That means they need to be able to make independent judgments on what they need to do, how are they doing, and why are they doing it. When they take a job as researcher or teacher, they cannot rely on their advisor/teacher to tell them the next step or to provide evaluation. On the contrary, they would be in trusted with training and evaluating the future students.

One way to examine this transition is through studying graduate students’ epistemological beliefs [31]. The definition of epistemology in the dictionary is:

The theory of knowledge, esp. with regard to its methods, validity, and scope. Epistemology is the investigation of what distinguishes justified belief from opinion. (Oxford Dictionary, Version 1.0.2, Apple Computer Dictionary)

The epistemological beliefs I will be referring to here mean the beliefs students hold about how knowledge is known and how knowledge is learned [32, 33].

Physics graduate students are students, teaching assistants, and apprentice researchers at the same time. In this dissertation, I suggest that they will hold some beliefs about learning, teaching, and research. I will show how their beliefs about
learning, teaching, and research influence how they perceive their learning environment (the learning environment where they learn the materials, learn to teach, and learn to do research). I will show how graduate students’ beliefs also affect what kinds of approaches they take in learning, teaching, and research, which then further influence the learning outcome. There have been some attempts to study epistemological beliefs of physics undergraduate students and how these beliefs interact with their learning [33, 34], physics faculty’s beliefs about teaching [1], and teaching assistants’ beliefs about teaching [35]. Although there have been studies of researchers’ views of research [36] there has so far been no study on graduate students’ views about research as they are going through the process of becoming researchers.

Before we try to provide an intervention to help graduate students hold more desirable beliefs or to change their beliefs, we need to know what kind of beliefs about learning, teaching, and research they hold in the current graduate program. We also need to have a better understanding of why they hold such beliefs about learning, teaching, and research, and how their beliefs interfere with or support their choice of approach. With a better understanding of the mechanism behind students’ beliefs, motivation, and behavior, it will be possible to create a coherent picture of the process by which physics graduate students transition from students into physicists.

1.4 Research Questions

The activities in which graduate students engage in their studies are: learning through taking classes, teaching as teaching assistants, and participating in research. These activities seem disconnected on the surface, but both teaching and research are deeply related to learning. Graduate students’ epistemological beliefs not only
may affect their learning approach, there might be some connection to how they view teaching and research as well [31].

Physics graduate programs take various instructional approaches in different settings. The graduate courses are taught with direct instruction, while students learn to do research with an apprenticeship model. The assessments that are used to measure students’ accomplishments are sequestered problem-solving for courses and PFL-type assessments for research. The two types of assessments have fundamental differences that promote very different kinds of learning approaches.

In undergraduate PER studies we have been concerned with how to help students learn each specific physics concept better (see [2] for a list of relevant studies). This is probably not a central question when examining graduate student education. We can presume that graduate students are relatively good at learning physics, but learning physics is not the only goal for graduate study. I will suggest that graduate students are expected to develop transferable scientific abilities [15] that they can use later for research and teaching.

The core idea that I will present in this dissertation is that the goals of the program, the activities, and assessment methods all interact with 1) student motivation, 2) students’ epistemological beliefs, and 3) students’ approaches to teaching and learning. In other words, the graduate education system is a strongly interacting system where goals, activities and assessments (the learning environment) interact with each other and with students’ learning goals, motivation, learning, and beliefs about knowing, learning, and teaching.

This motivates the set of research questions that I will investigate:
1. Students take core courses in which knowledge is provided to them by a lecturer, then they are expected to join a research group and become generators of knowledge rather than receivers of knowledge. We can ask: How does this transition happen? Do the core courses facilitate or hinder this transformation? And in turn, how do students’ research experiences before they enter graduate school affect their approaches to learning in graduate school?

2. Through their interaction with the various activities of the graduate program, students develop beliefs about knowing (epistemological beliefs). How do the various activities affect the development of those beliefs? This is obviously intimately tied into the first question of how graduate students make the transition from student to researcher. I will attempt to explore this in this dissertation.

3. I have suggested that students transfer their learning experiences and beliefs about knowing to their own teaching activities. Since the sustainability of PER reform is an important question in our field, it is important to ask how graduate students’ experiences and beliefs affect their views about how they should teach undergraduates. For example, we “throw graduate students into the deep end” and expect them to teach without an model of teaching other than their own classroom learning experiences, understanding of their students’ prior knowledge and expectations, or methods of evaluating their success or failure as teachers. How does this affect graduate students’ attitudes and approaches towards teaching? This is something I will investigate in this dissertation.

1.5 Outline of the Dissertation

In Chapter 2 I will present a literature review that will examine
1. Different ways of modeling the learning environment of graduate school.

2. Studies about how students develop more sophisticated epistemological beliefs. Especially, we study how students develop epistemological beliefs that are necessary for them to become effective researchers. I will examine studies that consider how their development is affected by their learning experience.

3. Studies of undergraduate research experience in science and engineering.

4. Studies dealing with teaching assistants.

In Chapter 3 I will suggest that graduate student learning is part of a complex system and that we might need to define the parameters of the system and how they interact. I draw together the ideas presented in Chapter 2 and present a theoretical framework that identifies the various parameters of this complex system and suggests ways in which they interact with each other. This in turn will guide the direction of inquiry into the various aspects of graduate student learning that will follow.

In Chapter 4 I will present an interview study with the general results from fifteen graduate student interviews. Here I will show how physics graduate students perceive their learning, teaching, and learning to do research. This chapter represents the quantitative aspect of my observational study.

In Chapter 5 I will look at some of the interviews in detail, presenting individual case studies. Case studies reveal more clearly how each student’s learning experiences influence her/his approach to teaching and research. This chapter represents the qualitative aspect of my study.

In Chapter 6, with what we learned from the literature and the results of this study, I will present a re-evaluation the physics graduate program. I will propose possible
ways in which we can change the program to help promote the goal of preparing graduate students to be future researchers
CHAPTER 2

LITERATURE REVIEW

There are four parts in this review. In the first part, I will review published studies of graduate programs in general. These studies have revealed some general problems with graduate education and provided suggestions for improving all the doctoral programs. In this part, I will also include the physics-specific data that are available to give an idea of the comparison between physics graduate programs and graduate programs in other subject areas.

The second, third, and fourth parts of the review deal with learning, teaching, and research separately. In the first chapter, I have already shown that both teaching and research are related to learning. Even though the review is separated into three sections, the ideas in one section are very much related to those in others. Some of the studies should be included under more than one heading. I will start with learning, which includes both the studies about learning in general and about learning in the classroom setting. The studies about learning to teach or learning to do research will be in the teaching and research parts, respectively. In Chapter 3, I will point to explicit connections among the literature on learning, teaching, and research reviewed in this chapter.
2.1 Past Research in Graduate Education

There are a number of national studies dealing with graduate education for Ph.D.s [7, 14, 37, 38, 39, 40]. The general findings are similar across these studies. To simplify the review I will summarize the general recommendations for the Ph.D. programs from [40], including additional recommendations from other studies where necessary.

2.1.1 Provide Explicit Expectations for Doctoral Students

In these national studies of doctoral programs, the most common recommendation is that clear information be made available to the students about what is expected of them. A clearer idea about what the requirements are and what the norms of the program are might help reduce the time required for students to get their degrees and minimize the chance that they will drop out of the program after spending considerable time and energy working on it.

Among all the studies about student attrition in graduate programs, Golde [38] investigated reasons why graduate students drop out the Ph.D. program during their first year. He interviewed students who left from departments in science fields (Geology and Biology) and humanities (History and English).

For science students, the major reasons given were: 1) an incompatible department, 2) unhappiness with the advisor, or 3) an attractive job market. In contrast, for humanities students, some realized they didn’t want the lifestyle of the faculty. Others said that they found the expectations for graduate students to be very different from their experiences as undergraduates. As undergraduates, they were expected to learn the content. In graduate school, students were suddenly expected to master theory and methodology. The students expressed their surprise in statements such as
You’re not supposed to be learning content anymore. You’re supposed to know all the content. You’re supposed to be learning theory, and I’m not really geared toward that. [38]

It is clear from the research that those students have the expectation that learning is equivalent to being told the knowledge, and are not comfortable making the transition to constructing meaning and looking for structure contained within the information they received.

Students in the two science fields didn’t make this claim. It is not clear whether this is due to the fact that many science graduate students have undergraduate research experience so that they know what it means to do research or because the science major graduate students are never challenged to make an argument or to debate in graduate-level science courses. If it is the second reason, then the first year of the science graduate program may be failing to help students transition from learning by receiving to self-directed and self-reliant learning in which students are expected to make their own judgments.

2.1.2 Provide Adequate Mentoring

In most fields, the research advisor generally is the primary mentor for the graduate student. In physics, many students have minimal opportunity to know their research advisor or group before they decide to work with them. The recommendations here include offering students multiple mentors who can be from different disciplines or institutions, or even industry [7, 40]. This not only gives students a diverse source of views on their research work, it also gives them a chance to have connections to other career options.
The studies also recommend that there be an institutionalized system for students to choose their mentor. In biology and some chemistry programs, there is a rotation requirement for all the first-year graduate students. Before they make their decision on choosing a research advisor, they are required to work on some research project with 2 or 3 research groups/advisors for an extended period (a quarter or a semester) [38]. Some programs even include an end-of-rotation presentation to ensure each student has done a fair amount of work with each research group. If students have a sufficient amount of working experience before they choose their research advisor, the chance that students will need to switch advisors or groups in their graduate study later on decreases.

2.1.3 Provide Exposure to a Wide Variety of Career Options

When students were asked what are the factors made them decide to go to graduate school, 78% of them expressed a desire for deeper knowledge in their field. A total of 66% expressed a desire to do research in this field, and 40% expressed a desire to teach in higher education [37].

From the results of a nation-wide survey [7], a majority of doctoral students (63%) considered becoming a faculty member to be their ultimate career goal. This number varies by field. Some 75% of mathematics students aimed to become faculty, while only 36% of chemistry students shared this goal. Interestingly, doctoral students’ desire to pursue an academic career decreased as they progressed through their graduate careers.

In contrast with the expressed aims of graduate students, an AIP report surveying almost 34,000 physics Ph.D.s in the US found that only 34% were able to obtain
an academic job after graduating [9]. When the participants were asked what their primary job description was, only 13% out of the total respondents answered “research work in an academic setting,” while 17% chose “teaching” as their primary job description. Ten percent of physicists obtained a research job from a government institute; an additional 18% had a research job in the private sector. In summary, a large proportion of Ph.D. physicists find a job outside of academia.

What graduate students don’t realize is that there are many more Ph.D.s produced each year than there are open faculty positions. In addition, many of those faculty positions are more focused on teaching than on research. Thus, it is important for physics that graduate students need to be made aware of the possibility of pursuing a non-academic job in the future.

2.1.4 Prepare Students to Teach in a Variety of Settings Using a Range of Pedagogies Based on Research in Teaching and Learning

While most graduate students hope to get a faculty position, they know little about what faculty actually do. A comprehensive, nation-wide survey shows [7] that full-time faculty across the university spend their weekly time as follows: Teaching averages 29 hours per week, including preparation, grading, office hours, and student advising. Service activities and administrative tasks take another 11 hours per week of faculty time. Research actually only occupies an average of 9 hours of faculty time. One-third reported spending just 1-4 hours weekly on research.

From the national survey, the result of students’ preparation for teaching varied strongly by discipline [7]. In general, graduate students felt prepared to lead a discussion section or teach a lab, but only slightly more than one-third said that they
felt prepared for lecturing to a large class. In physics, the situation is similar. Most of physics graduate students teach as teaching assistants to receive financial support. While they are supplied with complete teaching materials, they also have very little chance to be part of planning process of the courses. The majority of them teach introductory courses. Very few would have chance to be part of teaching team in the higher-level courses, and most of those who do, do so as graders. Physics education researchers have done relevant research on TA training. I will discuss those studies in Section 2.3.

There are three more items in the list of recommendations for Ph.D. programs.

- Recruit women and students of color to diversify the American intellect.
- Produce scholar-citizens who see their special training connected more closely to the need of society and the global economy.
- Balance the deep learning of the disciplinary doctorate with the variety of interdisciplinary challenges.

Because these are not directly relate to this study, I list them here without elaboration.

### 2.2 Learning

The literature on learning constitutes the largest of the remaining three sections of this chapter. First, there are many studies about learning from the fields of education, psychology, and cognitive research. The development of physics education research also contributes to the understanding of learning in physics specifically. The research on learning feeds into the research on teaching (Section 2.3) because research
on teaching generally makes some basic assumptions about the nature of how students learn. In this section I will review studies about motivation and assessment to understand how people are motivated to learn and how we can assess learning. Then I will review studies about epistemology, the theory of how we know what we know. These three areas (motivation, assessment, and epistemology) are the most important content-independent components of any learning environment.

2.2.1 Motivation to Learn

Teachers know this as a fact: Most students do not work on their homework until the night before it is due. No one has to force these same students to play a video or computer game. Students seem happy to spend all their free time on them. The key difference between the two activities is the motivation that drives students to engage in these activities. Here, I review some motivation studies to see if there is any way to understand what makes doing homework so different from playing a video game. When people learn (learning here is broadly defined as any kind of learning, it could be, for example, learning schoolwork or mastering a computer game), they take different approaches due to their goal orientation [41].

These possible goal orientations include:

1) Mastery: “I want to learn”

Learning with a mastery goal is exhibited by a person who plays a computer game. He/she persists at the activity, learning from his/her mistakes. He/she does not stop practicing just because she/he fails to win. For example, children don’t quit learning to walk just because they fall once. The goal of learning is to master the skill, so they don’t stop practicing until they can do it successfully.
2) Success: “I want to be the best”

Some people play sport to enjoy the feeling of success. They practice to be the best. They are always looking for competition. They work hard to practice their skill to be able to win the game. People with this kind of learning goal will be more likely to quit learning when they don’t perceive that they have a chance to succeed. Typically these are the students who ask what they need to do in order to get an “A”.

3) Avoidance: “I don’t want to fail”

Learners with an avoidance goal take the approach of avoiding any sort of failure. They take the safest approach to avoid making mistakes. They won’t try out an approach until they are sure it is the right way to do it.

4) Strategic effort: “I want the biggest bang for my buck.”

Learners with a strategic effort goal try to avoid work. They will try anything that promises to minimize their effort.

Research has shown that goal orientation (or learning approach) has a big effect on how one learns and on what is learned [42, 43]. Educators generally prefer students to approach their learning with a mastery goal. To achieve that, the first step is to understand why students might choose other approaches.

To understand the driving force that motivates learning, some motivation studies focus on where learners get their motivation, whether it is from an external source or from within themselves [28, 29].
1) **Extrinsic Motivation**

Extrinsic motivation describes a situation in which the learners are motivated by an external force, for example, to receive rewards or to avoid punishment. Most students are motivated by the grades — they complete the assignments that contribute to their grade but tend not to work on assignments that are not for points. When the extrinsic motivation is removed, the learner is less likely to perform the task voluntarily compared to a student who had not been given any reward or punishment at all [29].

2) **Intrinsic Motivation**

Intrinsic motivation refers to motivation that comes from within the learner. Learners choose to perform the task because of the enjoyment of learning itself. Learners driven by intrinsic motivation will practice the task with the goal of being able to master the skill. They would also prefer to take a deeper approach to their learning, which generally leads to better understanding. These learners are less likely to give up when they face difficulties with the task. One study shows that children's intrinsic motivation decreases with age [44].

Some studies try to classify student motivation on a scale from extrinsically motivated to intrinsically motivated, but this is not very practical since extrinsic motivation and intrinsic motivation are likely to co-exist and interact with each other. Researchers have shown that extrinsic motivation can either promote or undermine intrinsic motivation, depending on how it is used [28, 29]. For educational purposes, since it is neither practical nor possible to eliminate extrinsic motivation completely,
instructors should focus on providing extrinsic motivation that encourages students to develop intrinsic motivation.

Other motivation studies differentiate motivation based on the learning goal learners perceive. Due to the difference in goals, when learners engage in a particular task, their focus will vary. (See reviews by [29] and [45].)

1) Ego-involved

Ego-involved learners engage in a task to achieve end results that are not related to the task itself. Those end results could be to get better grades, or to be the first one to finish the work. Because success in comparison to others is the goal of learning, ego-involved learners quit doing the task when they don’t perceive a decent chance of reaching the goal. Ego-involved learners don’t persist in working on the task when they face more than minor difficulties.

2) Task-involved

Task-involved learners engage in a task for the innate enjoyment of learning the task itself. Since learning the task is the goal, when task-involved learners fail at some part of the task, they continue to work on the task until they finally master it.

The goal orientation of a student can have a profound effect on how he/she learns and on what is learned. Benware and Deci [42] gave students an unfamiliar passage on neurophysiology to study. The passive orientation group were told that they would be tested on how well they had learned the material, while the active orientation group were told that they had to prepare to teach this material to some other students after reading it. They gave both groups of students a test after they had completed the reading. The group who were told they were expected to teach the material to others
scored higher on conceptual understanding than the group who learned solely to be tested. The “learn to teach” group also showed more interest in the material and approached their learning more actively. On the other hand, there was no difference between the two groups on the score of a rote recall assessment. This shows the importance of carefully examining what a particular assessment is actually measuring. In this case, recall was unaffected by goal orientation, but deeper understanding was sensitive to students’ initial goal state. In addition, assessment types can affect students’ goal states. In Section 2.2.2 I will examine some of the existing assessment research to elaborate the connection between students’ goal states and assessment.

How does the research on motivation apply to instruction? Most people enjoy playing video games. Clearly there is some intrinsic motivation involved since people keep playing the games without much external reward. At the same time, not all games are equal. Some games are more popular than others. Other than personal preference, why do people pick one game over the other? First, the difficulty level of the game has to challenge the person playing it, but the game should not be so difficult that it is impossible for the person to make any progress in it. At the same time a game that is too easy wouldn’t be popular either. No one would be interested in playing an unchallenging game. The level of difficulty of the game should be moderately challenging to the person who is playing in order to catch their interest. The same goes for learning. If the task is too difficult for the students to think they can accomplish it, they won’t put in any effort. If the task is too easy, there is little feeling of accomplishment after completing it [28], and so also little motivation to do the task.
Secondly, the goal of a successful game needs to shift with time. No one wants to do the same crossword puzzle twice. There is no point of doing the same puzzle again when you can simply recall all the answers. On the contrary, people get addicted to playing the same computer game over and over when they try to finish it faster or to get a better score each time. Unfortunately, most students view any end-of-chapter problem in physics as a task with one fixed answer. When they get that answer, there is nothing more to be worked on.

The approach people adopt on playing games depends on the structure of the game as well. In a game with only one way of achieving a goal, the player would just memorize all the steps and repeat them to achieve this goal. On the other hand, if a game has many (or unlimited) possible ways to reach the goal, the player is more likely to take a more complex approach: analyzing the task structure, testing ideas, breaking down the task into parts, planning, and comparing strategies.

From the foregoing discussion, it seems that the goal of education should be to develop learning environments in which students are exclusively intrinsically motivated and the task involved is moderately challenging and can be accomplished in multiple possible ways. However, researchers have suggested that abandoning extrinsic motivation completely is neither possible nor practical [29]. Since most extrinsic motivation in school settings appears in the form of assessment, I will review the assessment studies to help understand better the connection between assessment and motivation. In particular, I will examine how assessment can promote deeper learning approaches.
2.2.2 Assessment

Some possible goals of assessment are a) to measure students’ knowledge state (how well they have learned something) and b) to assess the effectiveness of the instruction. Traditionally, the reason to assess students has been solely for the purpose of placement, which means to assign grades to decide who passes the course [46]. However, assessment can do much more than simply assigning grades. Assessment can be used to give students feedback to help them learn better. The information collected from assessment also provides feedback to the instructor and can be used to modify instruction [6].

What is assessed depends on the learning goal that an instructor has for his/her students. If the goal of learning is limited to content knowledge, assessment is used to measure how much of that information the students correctly remember. As already discussed, this cannot be the only purpose of education. After students leave school, they are going to need to apply what they have learned in a totally new content area. They are going to solve problems they have never seen before. If we wish students to be able to transfer what they have learned into a new situation, the goal of instruction needs to include more than content knowledge; we also need to help students develop skills they can use in new situations. In order to measure those kinds of skills, we need to rethink of how to assess beyond end-of-semester paper and pencil tests [5].

Researchers have divided assessment into three broad categories: diagnostic, summative, and formative [47, 48, 49].

1. **Diagnostic assessment:** Diagnostic tests are normally given before instruction for instructors to collect information about what students know. I will not consider this type of test in this dissertation.
2. **Summative assessment:** Summative assessments are used at the end of instruction to measure the result of instruction. Most of the commonly-used tests such as midterms, final exams, or even quizzes are all summative assessments. Students take the test, then they receive a grade from the teacher without further feedback. With the purpose of the test to give students fair grades that they deserve, the most important issue for a summative assessment is its validity.

3. **Formative assessment:** In contrast with summative assessment, formative assessments are used to collect information in order to give students feedback, and for the students to use this feedback to improve their learning. The assessment also provides the instructor dynamic feedback about the effectiveness of his/her instruction and can allow the instructor to make changes in the course that enhance student opportunities for learning. It doesn’t matter when the assessment is taking place. What is important is how students are given chance to improve their performance based on the dynamic feedback they have received [50]. The assessment doesn’t stop at the point when students receive grades on their exam. When formative assessment is used effectively it sends students a message that they have a chance to do better, and helps them to abandon their fear of failure.

I will now consider different types of assessment and how they measure what the instructor wants students to learn. Note that all these types of assessment may be administered in a manner that either is formative or summative.
Traditional Assessment

The common format of traditional assessment is a paper-pencil timed exam. The advantages of paper-pencil timed exams are that they are fair to everyone and easy to administer. The types of questions students can encounter in these kinds of exams are limited to multiple-choice, problem-solving, and short essay questions. The advantage for multiple-choice and problem-solving questions are there is no ambiguity about the correct answer as long as the questions are well written. There is only one possible answer as a single choice or a number that makes the grading of exams easy, clear, and fair. While short essay questions may permit more than one possible answer, they are often geared towards one correct idea. For the exams to be fair to all the students, the problems and answers have to be kept secret from the students until the exam [46]. The exams should randomly sample all the content that students have learned, thus making them suitable for measuring the content knowledge students have acquired.

Performance and Authentic Assessment

Concerns about the validity of traditional paper-pencil timed exams have led researchers to consider other ways to assess students. Performance assessment or authentic assessment has the goal of measuring student performance in a designated task or task that is similar to a real-world task [47, 49]. Most performance assessments have open goals, which means that the key (equivalent to the answer key of a regular exam) of the assessments is shared with the students before the test. The students know ahead of time what they are expected to perform in the tests as well as the criteria for good performance. This kind of assessment has been used in the field
of performance art for a long time. Dance students would be dancing and voice students would be singing in the test. They know what is considered good dancing or good singing before they take the test. In science education, instructors have started to adopt the idea of measuring how well students can perform in a science-related task [51]. The disadvantage of this type of alternative assessment is that there are no black-and-white-clear answers and they normally take a longer time to administer. The advantage of this type of test is that one can actually figure out whether students have the ability to perform the assigned task in an authentic setting.

Whatever type of assessment one chooses, the advantages of administering assessment formatively are well established by research. In an extensive meta-analysis of research in assessment, Black and Wiliam [6] found that successful application of formative assessment was one of the single most important factors in student learning gains. There has been some research in physics trying to help instructors to apply assessments in a more formative way [52, 53, 54]. For example, in trying to help students to think like a scientist and be able to conduct a scientific investigation, the Rutgers group have created a complete set of scientific ability rubrics [15]. The rubrics attempt to include all the abilities students might need to learn and define how these abilities are measured. The rubrics are shared by instructors with their students, before and during instruction. Thus students know “where” they are going. Feedback, based on the rubric criteria, aims to help students understand how to get to the ultimate goal of developing certain scientific abilities and assess where they are at a particular moment. Students can use the feedback from the instructor to improve their performance. At the same time, they can practice monitoring their own progress through self-assessment [5].
2.2.3 Epistemological Development

When students learn in a physics classroom they not only bring their prior knowledge into the classroom with them, they also bring with them their own beliefs about how knowledge is developed and what it means to know something. For content knowledge, instructors need to know what and how much students know in order to design effective instruction. Students’ fundamental beliefs about knowing and learning strongly interact with their approach to learning. Thus an instructor also needs to understand students’ epistemological beliefs in order to promote a deep learning approach [33].

There are several studies that attempt to categorize students’ epistemological beliefs. Perry attempted to sum up students’ cognitive development into nine different levels with the data he collected from his Harvard undergraduate students [55]. Later on, Belenky, Clinchy, Goldberger and Tarule studied women’s ways of knowing [56]. Their research revealed other aspects of students’ epistemology that Perry failed to observe from his male-dominated subjects. Kitchener and King came up with a seven-stage developmental model of people’s justifications for why they believe something. They called this the “reflective judgment” model [57, 58].

Although each of the above models focuses on different aspects of epistemological beliefs and there is no clear one-to-one mapping between models, the models share some common elements among each other. From these studies, we may infer common trends in the way students develop their beliefs about knowledge and knowing.
1) Beliefs about Knowledge Move from Certain to Uncertain.

In early stages of life, young students think everything is either right or wrong, that all knowledge is certain. There is no gray area in the correctness of the knowledge. Perry called this “dualism” in his study [55]. As their epistemological beliefs develop, students start to acknowledge that knowledge in some areas is uncertain or debatable. If the proper learning environment were provided, students would have better chance of developing the expert-like view that knowledge can’t be certain in any area. Each person has to make the judgment based on the evidence from the appropriate context.

2) The Source of Knowledge Moves from External Authority to Oneself.

In the early stages, students rely on external authority to provide knowledge. The external authority here could be teachers or books. They expect instructors to present the information clearly while they are merely passive recipients of that knowledge. Students also believe that only authority can decide what is right and what is wrong. On the contrary, the expert-like epistemological belief entails the idea that knowledge is meaningless until individuals construct meaning by connecting the new information to existing knowledge structures. Information from authority and peers are equally weighted until the individual has passed her/his own judgment [57]. The important key for the switch of beliefs about authority is the development of critical thinking abilities. As beliefs about the source of knowledge shifts from external authority to themselves, students also reduce their dependence on external evaluation and start to trust their own judgments.
3) The View of Knowledge Structure Moves from Disconnected Pieces to an Integrated Whole.

In the early stages, students treat knowledge as disconnected pieces. Knowledge from different subjects or topics is seen as unrelated to each other. Students don’t see the connection between what they learn in the classroom and everyday life. As their epistemological beliefs develop, students start to take what they have learned and connect it together. They start to construct their own structure of knowledge. Gradually students adopt the expert-like view that knowledge is an integrated whole.

Patricia King also summarized the common finding from similar cognitive development studies [58]:

1. People actively interpret and make sense of their experiences.

2. Reflective thinking develops over time.

3. The development of thinking is dependent on the environment. (Including the intellectual challenge, quality of feedback, and practice without fear of making mistakes.)

4. People can span multiple stages of development simultaneously.

With previous studies as guideline, Marcia Baxter-Magolda conducted a 16-year longitudinal study on young adults’ epistemological reflections [59]. She interviewed 101 college students yearly from their freshmen year until eight years after they had graduated. The reason I have chosen to use her model is because her post-graduate study included a large number of students (22) who attended graduate school. The other reason is that Baxter-Magolda focuses on finding what factors promote students’
epistemological development. From her data, she grouped students’ beliefs about knowing into four categories.

1) Absolute Knowing

Absolute knowers think all knowledge is absolute. Everything is either correct or wrong. They view external authority as the source of knowledge and themselves as only the receiver of the knowledge. They expect the instructor to provide the knowledge and expect the instructor to present the knowledge clearly. Peers are there to share the information. Evaluation (exams) is used to test whether students have acquired the knowledge. Baxter-Magolda found that most of college freshmen use this way of knowing, and that nearly half of sophomores are still absolute knowers.

2) Transitional Knowing

For transitional knowers, knowledge in some fields is absolute while knowledge in some other fields is uncertain. Their belief about knowledge makes a transition from certain to uncertain. In the fields where knowledge is viewed as uncertain, the goal of learning becomes to understand the information and apply it. Students expect instructors to provide instruction that promotes understanding and application of the material. Peers are there to explore different possible interpretations. They don’t view their peers as possessing any valid knowledge. Peers are only there to fill in the missing information from the instructor or provide opinion for subjective matters. They want the evaluation to focus on understanding rather than memorizing.

Baxter-Magolda found that most college students are transitional knowers. Over half of sophomores, about 80% of juniors, and 83% of seniors hold this mixed belief about knowing.
3) Independent Knowing

Baxter-Magolda found that few students develop the belief of independent knowing in their undergraduate study. Only 16% of the seniors are independent knowers. Independent knowers acknowledge that different people have different views. They think that knowledge varies depending on whose perspective you take. At this stage, independent knowers struggle to strike a balance on listening to the opinion of their peers as well as their own voice. In the classroom setting, student involvement is where this kind of thinking takes place. Students learn by exchanging their ideas with other students and the instructor. They combine different viewpoints with their own ideas to make their own decisions. These students also expect the instructor to encourage independent thinking and to avoid judging students’ opinions.

At the fifth-year interviews, Baxter-Magolda found that 57% of participants used independent knowing. It is clear that the environment of work and graduate school promoted participants to move toward independent knowing, because for their work they were expected to evaluate multiple perspectives and make decisions accordingly.

4) Contextual Knowing

For a contextual knower, knowledge exists in a context and is judged by the evidence relevant to that context. Contextual knowers understand that they need to establish criteria for knowing and they start to take on the role of authority. When contextual knowers collaborate with peers, they emphasize exchanging ideas rather than gathering information. They also find ways to look for external support and guidance when they need it.
Only 2% of participants adopted contextual knowing in their senior year. Most participants made the transition to contextual knowing later, after they started working or during graduate school. From the post-college study, Baxter-Magolda [60] concluded that the new expectations from work and graduate school forced students to think about their beliefs of knowing. The change of environment also made them start to connect what they learned to their personal life. The environments they were facing had a great influence on whether this transition would happen or not. For example, Baxter-Magolda quoted a student from the interview of her original college study,

A friend who is a physics major said he was going to a physics seminar. When I heard the word seminar, I thought, “Physics has seminars? I mean, you can debate physics? And not be right and not be wrong?” — Reginald [32] (p.136)

Baxter-Magolda used this as an example to show Reginald making the transition to independent knowing. This shows the common belief among undergraduate students that knowledge in science is always certain, especially physics. Reginald later said,

Why did I never have the chance to be in an open situation with physics? I hated it [physics] - couldn’t stand it because I couldn’t use my own ideas.

This quotation suggests that the way physics classes are taught might not support students using their own ideas to learn physics. The lack of a chance for open debate in physics classes indirectly leads students to believe that physics is completely certain.

2.2.4 Summary for Learning

Andrew Elby studied the reason introductory physics students take a rote approach in learning physics [61]. He asked students what they would suggest “Diana”
(a fictitious student) should do if she wanted to understand physics; he also asked them the reason they themselves take a rote-learning approach. He found out that students actually understand what kind of approaches they should take to achieve deep learning. At the same time, they believe a surface approach would help them get better grades. The possible reasons (given by Elby) why students have such beliefs include: the fast-paced curriculum in physics forces them to take a less time-consuming approach, and the assessment in physics fails to promote deep learning.

For physics graduate students, we would like to believe that the students would take an active and deep learning approach when they are taking courses and when they are in other learning situations. Unfortunately, there is no study of physics graduate students’ learning approaches or of their epistemological beliefs. In Baxter-Magolda’s graduate school study, there are no students from a physical science department to give us some idea of how the graduate level physical science courses influence students’ beliefs. In this dissertation, I will focus on what epistemological beliefs physics graduate students hold for their learning and how the learning environment they perceive affects the way they approach learning.

2.3 Teaching

Another important activity physics graduate students engage in during graduate school is teaching. Graduate students teach as teaching assistants to get financial support as well as getting the teaching experience they expect to need in their future career.

In this section, I will review the epistemology of teaching. Namely, I will examine what kinds of beliefs teachers hold about different types of knowledge and what it
means to teach that knowledge to students. Finally, I will review the research that has examined the teaching goals of physics courses and physics instructors and compared those goals to the actual teaching activities of the same instructors. In this section, I will also examine some studies about training the teaching assistants and the findings of those studies.

2.3.1 Epistemology of Teaching

There are three different dimensions on which teachers could focus their teaching. These are 1) the transfer of content knowledge, 2) the process of constructing knowledge, and 3) how we know that what we know is true. Instruction can focus on any combination of the three dimensions, but I am going to suggest later that the best way to teach is to include all three of them. Only when the learners have made progress in all three dimensions can meaningful learning take place. Here we will look at instruction with teaching goals focused on each of the dimensions.

1) Teaching as Knowledge Transfer

In the knowledge transfer approach, a teacher may often approach the student’s brain as a *tabula rasa*, or “blank slate,” upon which the knowledge to be learned must be written [62]. In this approach, the teacher controls the classroom and his/her primary goal is transferring the information from the teacher to the students [63]. Knowledge and understanding are treated as objects that can be delivered from one person to the other [64]. Students may quickly learn the facts by memorizing them and solve physics problems by rote. However, research has shown that this method of teaching has little effect on students’ conceptual understanding of physics [17, 65, 66].
2) Teaching as Helping Students to Construct Knowledge

Researchers have shown that students bring many ideas with them to the physics classroom—ideas that they use to try to make sense of what they are learning. (See Driver and Easley [67] for a review.) In summary, students use their prior knowledge to make sense of new ideas they encounter. Teaching with this approach requires that the teacher take students’ ideas into consideration in his/her teaching.

Teaching students how to construct knowledge doesn’t mean they don’t learn the facts. The knowledge itself is what gets constructed. In the process, students not only learn the facts, but also learn the process of acquisition of scientific knowledge. Unfortunately, this process for students to learn to construct knowledge takes a longer time to carry out. It also requires the teacher to be well informed about constructivist pedagogy.

At the same time, the process by which students construct knowledge can be learned through receiving and memorizing in the same way as students learn facts. Students can learn the process of constructing knowledge without developing more expert-like epistemological beliefs. Being able to perform a complex process to generate information is not equivalent to meaningful, deep structural learning. A computer can perform a complex process with proper programming, but without a programmer telling the machine what to do next, a computer can do nothing. Any job that only requires following detailed instructions can be done by a machine. The lack of epistemological growth in undergraduate physics students has been documented by Redish, Saul, & Steinberg in the MPEX study [68]. In a large-scale pre/post survey of reformed introductory physics courses (courses that used constructivist-based reform elements such as interactive engagement methods, Washington tutorials, and
Workshop Physics) they showed that students’ epistemological beliefs declined over the course of one semester of physics instruction. For example, many students still held or increased their belief that authority (the teacher) is the source of knowledge and did not view themselves as the center of knowledge construction.

3) Teaching as Changing Students’ Epistemological Beliefs

The MPEX study shows that changing students’ epistemological beliefs is not easy. Teaching for epistemological development requires that the teachers treat students’ ideas as legitimate. The teacher gives student a chance to generate ideas and make meaning through discussion. The instruction is centered around students’ ideas rather than the teacher’s knowledge. The teacher functions as a moderator of discussion, rather than the controller [31].

Just as teaching students the construction of knowledge cannot be done without including the content knowledge, teaching focused on changing students’ epistemological beliefs needs to incorporate the content knowledge, the process of knowledge construction, and explicit attention to how we know what we know. An example of this is the ISLE curriculum [69].

In order to provide instruction that promotes students’ epistemological development, we need to understand students’ epistemological beliefs and how they develop. From the studies about students’ epistemological beliefs, researchers have given some suggestions on instruction. I summarize them in the following section.

2.3.2 Teaching Goals and Instructional Practice

What are the possible goals instructors could have for their teaching? In 1956, Bloom led a group of psychologists who developed a set of educational objectives,
generally referred as Bloom’s taxonomy, as a way to classify the learning objectives instructors set for students [70]. In the cognitive domain, the taxonomy consists of six levels:

1. knowledge,

2. comprehension,

3. application,

4. analysis,

5. synthesis, and

6. evaluation.

In the original study, Bloom et al. found that most school tests focus only on the knowledge level. That means students were asked to recall facts without requiring any higher-level thinking. The original assumption of the taxonomy was that the objectives were ordered from simple to complex and concrete to abstract, and that the mastery of the lower-level objective is a prerequisite for the mastery of the next level. Krathwohl [71] suggested that the hierarchical structure of the taxonomy is not as strict as originally conceived. Although the six levels still move from simple to complex, there is some overlap among the objectives. Krathwohl also proposed to reverse the order of synthesis and evaluation. Since these two cognitive skills are somewhat independent and the development of one is not a prerequisite for the other, I suggest that we treat them as the equally highest levels on the hierarchy.

Henderson et al. surveyed 30 physics faculty for their course goals [72]. The top three goals for students were that students should “know the basic principles
behind all physics,” “solve problems using general quantitative problem solving skills within the context of physics,” and “solve problems using general qualitative logical reasoning within the context of physics.” All three of these learning goals fall into the lower three levels of Bloom’s taxonomy, knowledge, comprehension, and application.

The Henderson et al. study surveyed only introductory physics instructors, so one might argue that the professor who is teaching the upper level or graduate level courses might hold very different goals. Keith Oliver’s dissertation involved interviewing physics professors about their teaching goals [73]. One of the professors in his sample was teaching an upper-level undergraduate course for physics majors. Oliver classified the goals for that course as limited to the lower three levels of Bloom’s taxonomy. From both studies, we see that most physics instructors focus only on the lower-level cognitive objectives.

How are instructors’ teaching goals related to their teaching practices? In his study, Oliver had the instructors assign weights to the goals they had for the course they were teaching. Then he estimated the proportion of time that the instructor devoted to each activity that would promote achieving each specific goal. He also looked at how much different activities counted towards the students’ final grade and what teaching goals these activities promoted. He found that the three instructors he interviewed were unaware of the disconnect between the importance of the instruction goals, the time spent on different activities, and the way the assessments were weighted. In short, instructors did not devote enough time or assign enough value to the things they regarded as the most important.
To study the same issue, Henderson and Dancy came up with a list for comparing traditional instruction practices with the PER-compatible practices [25, 74] (see Table 2.1). The traditional instruction practices are consistent with the teacher-centered instruction approaches, which means the instruction goals focus on the amount of material covered and the teacher has the absolute control of the classroom activities [75]. In contrast, the PER-compatible practices are consistent with the learner-centered instruction approaches. For learner-centered instruction, the focus is on student learning through practice. In a learner-centered classroom, teaching is not “a play following the script” anymore; classroom activities can be modified based on student learning progress.

In the studies by Henderson and Dancy, they found that the instructors generally have PER-compatible or mixed beliefs (express both types of beliefs) about instruction, but their self-described practices are generally traditional or mixed [74]. They also found that the instructor tends to give up the PER-compatible practices when students are dissatisfied. When the instructor actually held PER-compatible beliefs, and was willing to implement the new techniques, the problems of failing implementation were: (1) The instructor didn’t choose the techniques outside of her/his basic instructional model; (2) The instructor stopped seeking more information after gaining the awareness of the new techniques (they failed to learn the “how-to” and principle knowledge behind the new techniques); (3) The planning was overly optimistic and it didn’t take into account the possibility of problems with implementation; (4) The implementation was limited by the instructor’s belief about external constraints on instruction.
Traditional Practices | PER Compatible Practices
---|---
Teacher ideas are center of classroom activities, students are allowed to be passive (e.g., lecturing, teacher-centered discussion). | Student ideas are center of classroom activities, students are often required to be mentally active (e.g., individual reflection, small group discussion).
Encourage or support competitive/individualist learning modes (e.g., grading on a curve, only individual assignments) | Encourage or support cooperative learning modes (e.g., grading based on preset standard, expectation of working with others)
External Motivators (grades, testing) | Internal Motivators (connections to student interests or needs)
Assess for quick and accurate performance in solving a set of familiar problems or in recalling a set of facts and principles. | Assess for thinking/problem solving skills in conjunction with meaningful understanding of facts and principles (i.e., open-ended or novel questions)
External definition of success for all students, same instruction for all, diversity seen as a problem. | Treat students as unique individuals with different needs, value all students
Grades/testing used to sort, rank, certify | Assessment for feedback
Major decisions made by teacher (content, focus, how class time spent) | Students contribute to decisions about what/how they learn (e.g., projects).
Explicitly teach only physics content. | Explicitly teach learning, thinking, and problem solving skills in addition to physics content.

Table 2.1: Comparison of instructional practices: This table shows the difference between traditional practices and PER-compatible practices [74]
Lin et al. [76] used a Q-type instrument to study the perceptions of students and instructors for physics laboratories. The result shows that when the survey response was grouped by instructor-centered verses student-centered, there is a mismatch between how students perceived the labs were taught and the teachers’ description of their instruction. The result also shows that the overall format of the laboratories might have bigger influence on students’ perception than the instructors’ instructional approach.

To study the effect of teacher training, Otero and Nathan analyzed how teachers described their students during interviews about teaching [35]. While none of the interview questions were about their view of students, the interviewees mentioned students quite frequently. They coded every passage in which the interviewee mentioned students into three categories: property of the students (smart or dumb, good or bad), condition of the students (having misconception, get it or not), and learning process (need to construct understanding, need to try out their own idea). Science course faculty talked about students equally spread in all three modes. Teacher candidates (teaching certified students) spent two-thirds of the time talking about the condition of the students and one-third on the student learning process. The Learning Assistants, undergraduate students who were recruited in this teacher training program though a special path that includes experiences in PER reformed courses, talked mostly about the student learning process [4].

2.3.3 Summary for Teaching

In this section, I reviewed three possible conceptualizations of what it means to teach: namely 1) to transfer knowledge, 2) to help students construct new knowledge
and understanding, 3) to help students develop beliefs about the nature of knowledge and knowing (epistemological development). In Chapter 3, I will suggest that rather than focusing on one of these ideas separately, for instruction to be successful, we need all three of them. These beliefs about teaching directly affect the teaching goals that instructors have for their physics classes. I also reviewed the research that shows that, although instructors may be able to articulate some or all three of these teaching goals, their instructional practice may only promote knowledge transfer while ignoring knowledge construction and epistemological development.

### 2.4 Becoming a Researcher

Learning to do research is one of the most important goals for students in a physics graduate program. Graduate students don’t receive their degree by passing the courses, but by completing their research work. Unfortunately, there is little research on how physics graduate students develop into successful researchers or what factors promote this development. There have, however, been studies on undergraduate research experience that provide some information about how students benefit from research experience and how the advisor-student interaction affects the result of this experience. I will review some theoretical models that might provide some possible ways to help students learn to do research and become a researcher.

#### 2.4.1 Undergraduate Research Experience

Graduate students are not the only group to have real research experience. In the physics department, it is quite common for undergraduate students to do a research project with a research group. Undergraduate research was, until recently, unstructured; any outcome was up to agreement between professor and student. A few years
ago, the National Science Foundation began a program called Research Experience for Undergraduates (REU) [77]. The program provided funding for science and engineering departments to offer summer research opportunities to undergraduate students from other institutions. Students work with the research group of their choice for one summer on some specific project. At the end of summer, students are required to write up a paper and give a presentation to the other REU participants. Since then, researchers have started to pay more attention to the effects that the undergraduate research experience has on those who participate in the program.

There are several REU studies focused on whether the research experiences promote students to pursue graduate study [78]. (Also see a review by [79].) These studies show that a substantial fraction of students who participate in the REU program continue on to graduate study while very few students who do not participate in the REU program subsequently go on to a graduate program. However, these studies do not rule out the possibility that students chose to participate in the REU program because they planned to continue in graduate study and viewed the REU program as a gateway to a successful graduate career. In short, there is no study that shows whether or not the REU program has encouraged students to go to graduate school. Hunter [80] found that REU of itself didn’t propel students into graduate school, but rather the experiences fostered the idea of pursuing a research career for those who already planned to attend graduate school. At the same time, for a small number of students, the experience confirmed that doing research is not for them.

This dissertation will focus on graduate student learning. From this perspective, it is more important to look at how research experiences influence student learning.
There is no reason to believe that such influences are unique to undergraduates, and so we should be able to observe them in graduate students as well.

There is one study conducted by Hunter [80] that focuses on student cognition, and personal and professional development due to undergraduate research experience. The subjects were students and advisors from four liberal arts colleges who participated in one summer undergraduate research program. Although limited in terms of generalizability, this study gives some idea of what possible positive impacts research experiences can have on student learning. In unstructured interviews, students (46%) felt that they had learned something about the process of scientific research. In particular, students were especially surprised to find that doing research is very different from learning in the classroom. Consider one of the student quotations from this study:

It’s certainly very different from how it’s [science is] taught... It was definitely in doing research that I learned how science is done... I’ve gained an experience of what doing science is really like, and doing it professionally in the sense of what it’s really like to take data when you don’t know what the answer’s going to be beforehand, like in a laboratory course. And to test it against a model where you’re not sure if you’ve accounted for everything and to really [learn]... what’s acceptable for publication... It’s one thing to study science, but it’s another to work on and solve problems. [80]

Interestingly, this student expresses a view that studying science and doing research are two different things. It is certain that all undergraduate students taking science courses are required to take some laboratory courses in their fields. Yet it seems like the regular undergraduate laboratory course doesn’t offer this kind of insight. This is possibly because there is always an expected outcome for all the experiments students do in lab. On the contrary, an undergraduate research experience
offers students a chance to work on open-ended, uncertain, and unsolved problems. They are participating in the process of creating scientific knowledge. Supporting this idea, a study of first-year physics students’ perceptions of the physics lab, there is evidence that labs that focus on open-ended investigation and scientific process abilities (ISLE) [15, 69] encourage students to perceive their work as self-directed. In contrast, other physics labs (even reformed labs) that focus on developing the concepts in a more prescriptive setting leave students believing that experimental decisions are made by and knowledge comes from the teacher [76].

In Hunter’s study of undergraduate research, relatively few students (9%) reported gaining the ability to make important research decisions such as defining new research questions or proposing experimental designs to test alternative hypotheses. Only 3% of students reported becoming aware of “higher” epistemological ideas such as the idea that scientific knowledge is not fixed and is subject to modification. This could be due to the duration of the summer research program; it is only ten weeks long. Perhaps students didn’t have enough time to develop those more complex skills. Baxter-Magolda [60] has suggested that the undergraduate learning environment does not support the development of these more sophisticated epistemological beliefs.

2.4.2 Learning to be a Researcher

From the undergraduate research experience studies, we can see how learning to do research for students is very different from learning in the classroom. In the learning section, we see by the time they finished an undergraduate degree, most students have not developed an ability to use contextual knowing. In Hunter’s study, after the research experience, students seem to have developed some epistemological beliefs
about science, but very few of them developed higher-level ideas about knowing. It shows that doing research has positive effect on students’ epistemological development, but the undergraduate research experience is too short to have greater impact. For graduate students, who have a much longer research experience and have a chance to complete a full research project, we should expect to see them reach a higher level of epistemological development.

At the same time, undergraduate research studies also show that a small portion of students had negative experiences with their undergraduate research [80]. Learning to do research is nothing like learning in the classroom setting. Learning to do research involves more complex cognitive processes such as analysis, evaluation, etc. It is possible that developing these cognitive abilities may not be taught effectively using the traditional transmission approach to teaching. In these research programs, students learn to do research by working with researchers on a real research project. They learn through the process of apprenticeship and “situated learning”. There are two elements that are important in this research apprenticeship model.

1) **Legitimate Participation**

Students need to be legitimate participants in the research. In the apprenticeship model, apprentices learn the skills through observing and practice. Students can only learn the skills they get to practice. A student who only gets to do routine work such as cleaning test tubes will not make the same gains as a student who gets to be actively engaged in decision-making on how to direct the experiment.

Lave and Wenger [19] suggest a learning process called “legitimate peripheral participation.” Learners are treated as legitimate partners in a “community of practice.” They learn the skills by engaging in real practice with the guidance from the master.
and the “old-timers.” The newcomers start their practice from simple and low-risk tasks. After they gain the appropriate skills, they move on to work on more important and central tasks.

In the undergraduate research studies, one thing students commented on is their confidence in science. Through participation in up-to-date research, students feel they are part of a community of making knowledge. This helps them to move their way of knowing from an externally-directed view (knowledge from authority and judgment by authority), to an internally-directed view (they themselves are the makers of knowledge). That is the same idea as Baxter-Magolda’s “self-authorship” [81].

2) Cognitive Apprenticeship

Doing research involves so many complex cognitive skills that following a traditional apprenticeship model is not enough to allow students to gain all the research skills successfully.

In traditional apprenticeship, apprentices learn the complex procedure through observing the master working, but doing research involves several cognitive processes that generally happen internally, so that students would have little chance to observe them. Second, the ‘product’ of research is not as clear as in the traditional apprenticeship, so that students have little chance to monitor how well they are doing.

Collins et al. [20, 82] proposed a new way to adopt the apprenticeship model into instruction called cognitive apprenticeship. In this model, the instructor focuses on externalizing his/her cognitive and meta-cognitive processes to make them available for students to adopt into their own learning. Although the conceptual and factual knowledge are not the focus of learning, they will still be learned as they are used to demonstrate the cognitive process [83]. In addition, students learn how to reflect on
their own learning as well as to monitor their own progress. The instructor is not the
evaluator of the learning but instead the coach of the learning process. The instructor
provides students the guidance students need in the process of developing requisite
cognitive skills or abilities [83].

2.4.3 Summary for Research

The conceptual knowledge and physical skills needed by different research fields/groups
can be very different, but many of the cognitive and meta-cognitive skills for doing
research should be similar. Here I am suggesting using legitimate participation and
cognitive apprenticeship as models to guide the training of future researchers. However,
legitimate peripheral participation and cognitive apprenticeship were originally
conceived as models for teaching and learning. It therefore makes sense that we
should apply these models to the teaching and learning aspects of graduate education
as well. In Chapter 3, I will propose that graduate education should adopt these ideas
for both classroom learning and for teaching training. Graduate students can start
learning the cognitive and meta-cognitive skills while they are taking classes. This
may speed up the process of transition from classroom learning to doing research.
This would also help students to see the coherence of knowledge from the classroom
to doing research.

2.5 Summary

This chapter first reviews research on what is known about the learning environ-
ment of graduate school and how graduate students interact with that environment.
There follows a broad review of research on the three major activities of a physics
graduate student’s life that were identified in Chapter 1: 1) learning, 2) teaching, and
3) research. This review considered the different ways in which these three activities have been conceptualized by researchers and the major factors that may contribute to the development and promotion of learning and research activities in students. This review was focused particularly on the underlying theme of epistemological development because, as I suggested in Chapter 1, graduate students’ changing views about the nature of knowledge and knowing may be the key to understanding their intellectual development in the graduate program.
CHAPTER 3

THEORETICAL FRAMEWORK

In last chapter’s review, teaching, learning, and research were discussed separately. At first glance, these studies seem unrelated. Learning is about learners (the students) and how they learn, while teaching is about teachers and how they teach. Research is done in the lab where few things seem to resemble classroom learning and teaching. In this chapter, I am going to propose that learning, teaching, and research are in fact similar activities that share a number of traits in common. The fundamental idea that connects these three activities is the student’s, teacher’s, or researcher’s beliefs about knowing. From this perspective, I will show that learning, teaching, and research are actually closely related activities. I will use these ideas to create the framework for my research.

3.1 An Illustrative Example

In the preceding chapter’s review, I have shown that motivation and assessment individually correlate to student learning. Here I am going to propose that learning goals, motivation, and assessment can influence one another. Graduate students’ learning approach and teaching approach are the result of their perception of learning
and teaching environment. Learning, teaching, and doing research are similar activities with the same underlying assumptions of what knowledge is and what learning means.

### 3.1.1 The Connection Between Goals, Motivation, and Assessment

In the review, I have shown that goals, motivation, and assessment are important for learning. However, these three factors interact with each other. Assessment can be a major external driver of motivation. Students study the material because they will be tested on it. The assessment serves as an important clue for the students as to what the learning goals of the course are. A student’s perception of the intent of assessment then affects the type of learning that the student engages in. Thus it becomes imperative that a teacher’s learning goals are aligned with the assessments that he/she uses. Below, I will provide an illustrative example of how goals, motivation, and assessment interact with each other in the learning system.

A well-known PER professor, E. F. Redish, mentioned in his book, “Teaching Physics with the Physics Suite,” the first time he taught electromagnetism to sophomore physics majors, the material suddenly made coherent physical sense to him [84]. He also mentioned that he had studied electromagnetism with Maxwell’s equations five times from high school to graduate school. As a graduate student, he thought he understood the material by learning all the equations that enabled him to solve lots of difficult “Jackson” problems [85]. He didn’t realize that he hadn’t really “made physics of it” until he had to teach it [84]. The wisdom that “you haven’t really understood it until you’ve had to teach it” is common amongst physics teachers. Research studies support this idea: In a meta-analysis of tutoring programs, Cohen et al.
showed that students who had to tutor other students gained a better understanding of the material they were tutoring [86].

There are two possible reasons why this would happen. First, it is possible that the more times you study the same material, the better you will be able to remember it. But being able to recall something is not the same as understanding it. Otherwise, we could have students read the same material many times then they will eventually understand it. A second possible reason for the “learning by teaching” effect is that the expectation of teaching makes people approach learning differently.

Research shows that it is the type of activity that the student engages in while learning that makes a difference to whether they develop understanding or not. For example, students who were instructed to engage in self-explanation while reading an expository text (such as a physics textbook) learned more and developed better understanding than students who were not instructed to use this strategy, but simply re-read the text twice [87]. In Benware and Deci’s study they asked two groups of students to learn an unfamiliar text [42]. One group of students were told they would be tested on the material afterward, while the other group of students were told they had to teach it to someone else. The learning-to-be-tested group performed worse on tests of understanding than the learning-to-teach group. There was no difference between the two groups on recall measures. It is therefore possible that when a professor teaches a physics course, s/he is forced to organize the course material in order to be able to explain it to students, resulting in better and more coherent understanding.

Instead of jumping to the conclusion that we should try to have all students learn by teaching, it may be better to try to understand the mechanism behind this effect.
If we understand it better, we may be able to construct a learning environment that would promote students to learn as teachers learn any material to prepare to teach it to others.

Teachers find themselves able to understand the material better when they prepared to teach it. This demonstrates an interesting phenomenon. First, the motivation for the teachers has changed. The teachers are “learning” to prepare to “teach”, that means they are expected (and they also expect themselves) to have full understanding of the material before they go in to the class to teach. The learning goal of “preparing to teach” means to have full understanding and be able to communicate the material to others. Second, there is no longer any external evaluation to assess them. The teachers cannot rely on others to tell them whether they got it right or not. That means they have to develop some sort of self-assessment to monitor their own learning progress. By changing the learning goal to “prepare to teach,” the motivation of learning and the expectation of assessment are also changed at that same time.

In this example, I have illustrated two possible learning goals: one is remembering, the other is understanding. These choices of learning goals are influenced in part by the participants’ perception of what they are required to do. Their perceptions and motivation are influenced either by a) the external assessment (the exam) or b) by their own expectation of having to understand the material well enough to teach someone else.

Change one factor and all three factors shift. Changing the external goals from “learning to pass the exam” to “learning to teach” affects the motivation of the learners (more task-involved), which in turn affects their perception of the assessment
method (expecting external examination versus self-evaluation). But it was a shift in evaluation that sparked it all off in the first place! In the case of the learner who no longer has to pass the exam, but has to teach, he/she understands that there will be a problem if he/she cannot explain a particular concept to his/her students. No one would bother to assess every single topic a teacher teaches before they go in to a class to teach, so the teachers need to develop some sort of self-assessment ability to monitor their own learning.

In summary: In last chapter’s review we saw how motivation and assessment affected students’ learning approaches/outcomes separately. At the same time what a teacher thinks teaching means results in his/her choice of a more teacher-centered or a more student-centered teaching approach. Previous research has shown that learning goals, motivation, and assessment individually have a critical effect on students’ learning approaches, which directly relate to the learning outcome.

The example just covered above suggests that it may be productive to treat learning as a system in which learning goals, motivation, and assessment are in fact all part of the complex dynamical system [88]. They interact with each other and the overall effect cannot be explained by simple independent relations between the different factors and the learning outcome. While instruction changed based on the new learning goals, without modified assessment to reinforce the goals students would still be driven by the external motivation instead of motivated by the new goals. This may explain why some adoption of new instructional techniques do not always yield the expected outcomes. (Note, for example, the failures of many reformed physics courses to change students’ beliefs about knowledge in physics [68].)
If you look at teaching, learning, and research on the surface level, they appear to be quite different activities. However, if one chooses to examine a) the goals of people who participate in these three activities, b) the motivation that drives participants to participate in these three activities, and c) the methods by which one’s success in these three activities is evaluated, there are some remarkable commonalities that emerge.

In the following sections I am going to show how the three graduate student activities of teaching, learning, and research are related to one another by examining the goals, motivation, and assessment involved in each activity. I will show that a participant’s approach to each of the three activities is in fact determined by his/her perception or model of what knowledge is. A participant’s underlying epistemological assumptions appear to be the ultimate driving force that determines his/her perceptions of goals, motivation, and assessment, and his/her approach to each of the three activities.

### 3.2 Teaching and Learning

The learning goals, motivation, and assessment are closely related by the person’s conception of what learning and teaching actually mean. A teacher chooses his/her instructional approach based on his/her belief about teaching. A learner chooses his/her learning approach based on his/her belief about learning and what he/she perceives is the goal of the class. In this section I will present two possible models of the activities of learning or teaching. In each case I will show how the chosen model affects the learning or teaching goals of the learners/teachers, their motivation, and the role of assessment in the learning system.
3.2.1 Learning/Teaching as Transferring Knowledge from Teacher to Learner

Learners who believe that learning is primarily an act of receiving knowledge are equivalent to Baxter-Magolda’s absolute knowers and transitional knowers [59]. These learners can view learning as either passive receiving or active acquiring (the difference between men’s and women’s ways of learning) [59]. Irrespective of whether a learner is a “passive receiver” or an “active acquirer” the learner holds the belief that knowledge comes from external sources. Authorities provide certain and correct knowledge; non-authorities provide uncertain and doubtful knowledge. Knowledge is the object that can be transferred, received, and owned.

With the knowledge transfer model, the goal of learning is to acquire content knowledge. Learning is equivalent to receiving knowledge and then remembering and comprehending. In this metaphor, from the teacher’s perspective, knowledge is learned as the way it is presented. Teaching success is judged by how much of what is transmitted is retained by the learner. Assessments are used to measure whether students have acquired that knowledge, so a demonstration of recall and direct application is the main theme of the assessments. The instructor’s job is to deliver knowledge to students as clearly as possible and to give exams to measure if the students “got it or not.” Since students are only asked to demonstrate their knowledge by repeating what they have seen in the classroom, ego involved extrinsic motivation is enough to drive them to learn by rote. Learning is measured by the amount of knowledge acquired. The more they are able to recall, the better they have learned. In this model the best assessment tool is some form of summative assessment. The test has to sample a sufficient number of topics covered in the lecture. Since the
assessment is to repeat what was demonstrated in class, for the fairness of the test, the questions and the key has to be kept in secret.

How does this connect with teaching behaviors? This model is complementary to teacher-centered instruction. In the teacher-centered view, the teacher is the person who holds absolute authority in the classroom. The teacher also decides what to learn and how to learn it. The learning/teaching cycle proceeds in the following way: The teacher presents the content to be learned and students obtain it by taking notes and/or listening. At the end, the teacher evaluates students’ learning by summative assessment. Regardless of the result from the assessment, teacher moves on to the next topic in order to keep on the schedule of the material to be covered. A model of teacher-centered instruction is shown in Figure 3.1.

![Figure 3.1: A model of teacher-centered instruction.](image)

In the teacher-centered classroom teaching is evaluated by how clearly the material is presented by the teacher and whether the teacher is able to hold the attention of his/her students. If the teacher presents the knowledge with sufficient clarity, then it is the responsibility of the student to receive and process that knowledge. Professors
are seldom questioned when a substantial fraction of their students fail, they are more likely to be challenged when an inordinate number of their students get an A.

3.2.2 Learning/Teaching as a Process of Helping the Learner Construct Meaning

Learners and teachers who share a belief about learning as constructing meaning don’t treat knowledge as transferable objects. The content is the medium for learning but not the focus of learning itself. The goal of learning is to master all the learning skills like application, analysis, synthesis, and evaluation. Since the goal of learning is for students to master the skills that require a focus on practicing cognitive and meta-cognitive skills, it is vital for students to be intrinsically motivated to keep them from giving up when they fail. Ideally we want them to enjoy the constant challenge of the learning process and be willing to put in the time and effort to master the skills. Such students want to know how well they do, not by comparing with other students, but by evaluating the success by their own progress. They constantly asking themselves “does this make sense to me?” or “do I really understand how to do this?” They constantly evaluate how well they can use the skills that they have acquired. They would be able to tolerate challenging situations and wouldn’t give up easily because of initial failures.

With mastering skills as a learning goal, formative assessment should be adopted for this learning/teaching model. With clear rubrics that describe target performance goals, students have a clear idea of what they are expected to accomplish. Students also start learning how to monitor their own progress through self-assessment. The instructor’s responsibility now is not to assign grades but to give students constructive feedback that helps them improve their performance and gain mastery. Through the
process of self-assessment and instructor feedback, students not only learn the skills with scaffolding from the instructor, they also start to model and practice how to evaluate their own work and make judgments.

The learning through constructing meaning model is consistent with a learner-centered view of instruction. In the learner-centered classroom, students are active participants in the classroom activities. Students’ ideas are the center of the instruction, and instructor acts as a moderator to guide the discussion. The learning/teaching cycle for this model is far more complex than the knowledge transfer model. The cycle begins with the instructor modeling the skill(s) to be learned. Then the learner/student goes on to a practice and self-assess cycle until he/she is satisfied with his/her own performance. Then the instructor assesses students’ learning progress and provides feedback to the students to help them improve their performance. This assessment also helps the instructor assess the quality of his/her instruction. If the assessment shows little learning, the instructor modifies the instruction to help students learn the target skills better. The success of teaching is judged by student learning, not by the performance of the instructor in isolation. A model of learner-centered instruction is shown in Figure 3.2.

These two models of teaching and learning are summarized in Figure 3.3. The first model is in blue while the second model is in red.

3.2.3 Implications for Physics Learning and Teaching

In the ideal situation, the goals of learning, how the students are motivated, and what is measured by the assessment for a course should be all consistent with each
Figure 3.2: A model of learner-centered instruction including formative assessment feedback mechanisms.

Figure 3.3: Connections between goals, motivation, and assessment for learning and teaching.
other as shown in Figure 3.3. The way a student perceives the course goals, motivation, and assessment should be the same as the instructor to achieve the best learning outcome. It is obvious that the course goals students perceive could be different from the goals the instructor has in mind. And it is also common that the goals, motivation, and assessment for a course are not always matching either [25]. When students are taking a class, they most likely enter the class motivated extrinsically. They learn by following the goals of the instructor’s assessment, since getting an A is the main driving force for them to learn. If the exams only focus on problem solving, and getting the correct answers is what the students are tested on, there is nothing else students would try to learn regardless an instructor’s effort to teach more than that. It is often believed that problem solving measures understanding but this view has been questioned [89]. (Note: The term “problem solving” means different things for physics education researchers and for cognitive researchers. In physics education, problem solving generally means solving the ‘end of chapter problems’. Those are very typical physics problems that involve identifying the correct principle and choosing the correct equations to solve the problem. On the other hand, when cognitive researchers talk about problem solving, they normally mean solving a real world problem that is often open-ended. The problems generally are different from what have been shown in the classroom. Such problems require higher-level cognitive skills to complete. Here the term “problem solving” refers to solving typical physics problems.)

How does this apply to graduate education? As I have suggested in the first two chapters, the ultimate goal of graduate education should be to prepare students
for their future research and career. Physics graduate students should be learning for transfer. To have successful transfer, the learning goals should focus on the transferable skills. Then the teaching of the graduate program should adopt the learner-centered approach with formative assessment. The graduate students should be intrinsically motivated toward learning, and they also need to be helped to develop self-evaluation skills to monitor their own learning progress.

3.3 Research and Learning

It is possible to think of research as a type of learning. Research is what a researcher does, learning in an environment in which no one knows the right answer. It therefore would not be surprising if the driving factors behind research (goals, motivation, and assessment) are similar to the driving factors that underpin students’ classroom learning.

In last section I talked about learners who believe learning is a transmission of knowledge. I showed how this belief leads to a focus on learning as receiving information, driven by extrinsic motivational factors, and dependent on external authority for evaluation. In contrast, learners with beliefs about learning as constructing meaning are intrinsically motivated, focus their learning on the mastery of the task, constantly evaluate their own progress (self-evaluation), and develop the ability to make a judgment based on the information that is available. I am going to suggest that we can identify a remarkably similar distinction between product- and process-oriented views of doing research. In an interview study of 57 senior researchers’ conceptions of research, Brew identified four categories of research conceptions [36]. She categorized
these conceptions about research into *domino, trading, layer*, and *journey*. These four conceptions are underpinned by two research orientations:

1. The *domino* and *trading* conceptions are characterized by an “external, product” orientation towards research. In this orientation, the researcher is primarily concerned with getting results, applying techniques, and synthesizing facts (*domino*), and/or producing publications, and getting grants (*trading*). The researcher’s work is evaluated by peers, and social standing amongst a community of researchers is of central importance.

2. The *layer* and *journey* conceptions are characterized by an “internal, process” orientation towards research. In this orientation the researcher is primarily focused on the process of doing research either a) by illuminating/uncovering new truths about reality, or creating underlying meanings (*layer*), or b) by being personally transformed by the data and experiences that accompany the research process (*journey*).

It is also important to note that Brew found that these different approaches to research were not restricted to particular disciplines.

It is arguable whether these four categories sum up all the possible research conceptions, but from this study what is clear is that researchers hold different beliefs about what research is, and they value different aspects of research. Some researchers are motivated by external factors (extrinsically motivated), view research primarily in terms of its products, and view their success in terms of their social standing amongst peers (ego involved). They judge the success of their work in terms of how others
receive it. Their research interests are primarily constrained by whether a particular study will end in publications.

Other researchers are focused primarily on the process, the act of doing the research itself (task involved), and are motivated by the growth of their own understanding, or personal transformation that may occur as a result of their work (intrinsically motivated). Since their work is inwardly focused, they will necessarily judge and evaluate their progress in terms of the growth of their understanding or personal transformation. They don’t rely on external approval to judge their own or other researchers’ work. They tend to judge the information based on the available evidence, within the given context similar to Baxter-Magolda’s contextual knowers [59]. These two conceptions of research are summarized in Figure 3.4.

![Figure 3.4: Connections between goals, motivation, and assessment for research.](image)

In summary, just like learning, research can be intrinsically driven by a desire for a better understanding of the world. Or research can be driven extrinsically by a desire to get some external recognition like a grant, or a paper publication or better ranking.
or a promotion. The approach that a researcher may choose will vary according to different driving motivations and research goals. For example, a new professor who will be up for tenure in six years’ time is not likely to undertake a long-term longitudinal study that will only produce publishable results in ten years’ time.

3.4 Discussion

“You don’t take the four core courses and you’re done. Because if you were done, that’s all you’d have to do to get your Ph.D., right? And obviously that’s not true. No-one gets their Ph.D. just by taking courses.”

Justin, interview study.

One important element of the Ph.D. degree is research. Every graduate student who wishes to receive her/his degree has to demonstrate her/his ability to conduct research. But what do graduate students need to learn to become a researcher, and how do they learn it?

3.4.1 Locus of Authority

As I have suggested, research is a process of self-directed learning. The types of problems that researchers encounter are open-ended and do not have known answers. Sometimes researchers don’t even know if they are asking the right questions, or are on the right track. Researchers have to evaluate their progress continuously, making judgments, possibly reformulating the problem, and revising methodologies. A researcher expects to get suggestions and comments from the other researchers, but she/he won’t expect to have an external authority to tell her/him what questions to ask, which methods to apply, or how to make a judgment about the results. Researchers cannot rely on external authority alone, they have to rely on themselves. They have to view themselves as the authority.
One important factor that separates expert researchers and novices are their views on *locus of authority*. There are two important characteristics of authority. First, authority is the source of knowledge. Second, authority holds the power to make judgments. Novice physics students often see authority as located in or with external authority figures such as professors or textbooks. For them, learning is receiving information from authorities and they also expect to be evaluated by an external authority. They seldom question the claims made by an authority and judge the strength of an authority by his/her status. (For example, a professor holds more authority about the correctness of knowledge than a graduate student TA.). On the other hand, experts need to have an internal locus of authority. In other words, they view themselves as the source of authority or we can say they have developed *self-authorship* [81, 90].

“They assume knowledge is uncertain and judged in light of evidence relevant to the context; they actively construct, evaluate, and interpret judgments to develop their internal belief systems.” [91]

They don’t rely on an external evaluator to assess them. They are constantly self-assessing to monitoring their own progress. This ability of self-monitoring is how researchers can successfully conduct research in an unknown area.

### 3.4.2 Learning to do Research, an Analogy

Learning to do research is like learning to cook in some intriguing ways. Learning to cook by following a cookbook is possible, but it is never going to be the same as cooking with a good chef. The best way to learn to do research is to work with researchers on some research project. But watching a good chef cooking is not enough
for learning to cook either. When a chef is cooking, there is a lot of thinking, reason-
ing, and decision-making not showing in the act. To learn all those internal processes
from a chef the apprentice must rely on the chef to externalize those processes. In
other words, the chef needs to tell the apprentice what he/she is doing and why he/she
is doing it. Researchers have a lot of internalized processes: thinking, reasoning, and
decision-making, that is not obvious or easily seen by the graduate students. For a
student to learn how to go through this research process he/she needs to rely on the
researchers/professors to externalize their thinking.

At the same time, no one would be a good cook without actually doing the cooking.
Likewise, the best way to learn to do research is to actually working on it, but doing a
lot of research doesn’t make a good researcher just like doing a lot of cooking doesn’t
make a good cook. An important ability any good chef needs is to be able to taste
the food and make adjustments based on what is tasted. A successful chef cannot
rely only on the customers to tell him/her how the food turns out. A successful
chef is able to create new dishes on his/her own, using deep principled knowledge to
combine known ingredients in new and novel ways. Likewise a good researcher should
not only rely on external evaluation to judge whether his/her research is good or not.
Being able to self-assess in the process of research helps the researchers to make
proper adjustments and certain decisions to guide their journey in the unknown field.
This is one of the keys to a successful research outcome. Unfortunately, in traditional
science education, evaluation is normally based on external authority. Self-assessment
is seldom part of the instructional process. As a result, most students don’t develop
the ability of self-evaluation.
3.4.3 Developing Self-Authorship

Several studies on students’ epistemological development have suggested that through formal education college students have been socialized to depend on external authorities for their beliefs. They view knowledge from external authority as certain and unquestionable, and never develop the ability of critical thinking in order to make individual judgments [32, 91]. On the contrary, students who develop self-authorship in their education do not view knowledge as coming from an external source. Self-authored individuals would not take information as it is presented. When they receive new information, they need to process, reconstruct those information to make meaning for themselves. They would also try to make connections between the new information with the existing knowledge to form a complete picture. What’s more important is that during this process, self-authored individuals evaluate the information and make internal judgments. As a result of this change, they no longer absolutely take the word of an authority figure. They now view themselves as authorities who hold the power of deciding what’s right or wrong [81, 90]. In other words, for an individual to develop a concept of self-authorship, the locus of authority must shift from outside the individual to within the individual.

Successful researchers need to develop self-authorship. Just as a successful chef can’t exclusively rely on other people to taste the food, a successful researcher needs to have the ability to evaluate his/her own research progress. It doesn’t work for a chef if he/she can only cook by following existing recipes without making necessary adjustments. The same applies to the researchers. Research is essentially learning in an unknown area in which no clear instructions exists. At each point in the research
program, researchers evaluate their work and their decisions. Graduate students need to adopt self-authorship in order to transition from students to researchers.

3.5 How do Graduate Students Select their Approach to Learning, Teaching, and Research?

I have shown how beliefs about knowing can explain people’s approaches to learning, teaching, and research. However, this does not necessarily mean that the same person will hold the same beliefs across different activities, or conduct those activities within the same framework of beliefs.

Baxter-Magolda warned that it is not simple matter to categorize an individual into a single way of knowing because some people can hold different beliefs for different subject matter [59]. The typical case is that students think subjects like physics are certain and not open for discussion, while at the same time subjects like political science are open for debate and everyone can have his/her own opinion.

In a study by Wolff-Michael Roth [92], high school students were surveyed and interviewed to study their beliefs about the nature of science. Students viewed the knowledge they learned from the textbook/lecture and the knowledge they learned in the lab differently. The knowledge they learned from the textbook/lecture was second-hand information. They viewed the concepts provided by the textbook and teachers as objects to be memorized and regurgitated, because the school courses were taught in lecture format and students were rewarded for confirming the teacher’s view, the correct view. On the other hand, since the physics lab was structured in an open inquiry format, students felt that they were learning through interpreting data and generating their own knowledge. They viewed knowledge acquired in the lab as constructed by themselves, uncertain, and open to revision. They also indicated they
felt that the knowledge they learned in the lab was more related to their everyday experience. The lab also gave students a great deal of autonomy in learning. They were more motivated to learn in their own and viewed the knowledge as their own [92]. This study shows that the same student can hold different beliefs about knowledge in different contexts for the same physics course.

For physics graduate students, due to the complexity of their graduate career, the sorts of beliefs they hold is not an easy question to answer. Since they are working on a physics degree, most of the courses they take or teach are somewhat related to physics. Only a small percentage of them would be working on something totally unrelated to physics. For the case of physics graduate students, since most of them only take or teach physics courses, the difference between subjects is not important for this study. At the same time, for graduate students, they are taking courses as students, teaching as teachers, and doing research with the research group as apprentices. Their roles change from novice (when they are taking class), to authority (when they are teaching), to legitimate/illegitimate practitioner while they are doing research. There is no guarantee that their approach to learning would be transferred to their approach to teaching or approach for doing research. The reviewed literature suggests that it is likely that they will take on different approaches because of the different expectations that are placed on them and the way they perceive the environment. Like the students in Roth’s study, who take on different beliefs about physics knowledge when they are in lecture and when they are in lab, it is highly possible that graduate students might take on very different beliefs about knowing when they are in different roles.

First, from Baxter-Magolda’s study we know that most students don’t develop into contextual knowers during their undergraduate education. In addition, the level
of development they achieve is dependent on their undergraduate education. Second, the environment is strongly correlated to their choice of learning/teaching approaches. How the courses are taught, how the teaching is structured, and how the research group functions could all influence their choice of learning, teaching, and research approach. Third, since graduate students are learning, teaching, and doing research on physics at the same time, it is not surprising if there are some interactions among those activities. That is, they might choose a teaching approach based on how they learned; or they might take certain research approach because they have been successful with the same approach when they were taking courses.

### 3.6 Research Questions

From my observations, most graduate courses, especially the core courses, are taught in a traditional way, which is teacher-centered. When there is a suggestion about reforming graduate courses to make them actively engage students, physics professors comment that physics graduate students are expected to be active learners. In other words, the graduate students are expected to be active learners in a passive environment. In most physics education research, graduate students are viewed as experts for introductory level physics questions. In reality, graduate students are at the stage of transitioning from novices to experts in their research field.

In this dissertation, I plan to explore the kinds of approaches that graduate students take to learning, teaching, and research, and whether some of them transition from novices to experts during their graduate career. I want to understand how that process of development from novice to expert takes place. Understanding how this transition takes place will help us modify the program better to prepare physics
graduate students to become future researchers. In this chapter, we have seen that learning, teaching, and research are in fact closely related to one another. I would like to see if graduate students’ views about learning transfer to their views about teaching and/or research. If they do, they should be more motivated toward their learning since they will see the relevance of taking classes for their future teaching and research.

In summary, I will ask:

1. How do physics graduate students learn in the classroom setting? What are the course goals they perceive? How are they motivated to learn? And why do they take those learning approaches?

2. How do physics graduate students teach as teaching assistants? Why do they take those teaching approaches? How do they plan to teach in the future?

3. How do physics graduate students approach research? How and where do they learn to do research?

4. Is there a difference between graduate students in their first two years and those who are close to finishing their degree?

5. Most importantly, how do physics graduate students make the transition from students to researchers?
CHAPTER 4

METHODOLOGY AND OVERVIEW OF RESULTS

4.1 Methodology

Compared to students in introductory physics courses, physics graduate students are a much smaller population. With no previous study of this kind having been undertaken on physics graduate students, very little is known about how physics graduate students learn, teach, and do research. To get a better idea of what students do when they engage in these three activities, I chose to use semi-structured interviews to better understand how physics graduates approach learning, teaching, and research.

Most interviewees were volunteers from the OSU physics graduate program. Only one of the interviewees was not enrolled in the OSU physics graduate program. Two OSU interviewees had been students in another physics graduate program before they joined the OSU physics graduate program. These three students were able to give some valuable insight into other physics graduate programs and provided additional validity to the research.

There are two ways to study the evolution of students’ beliefs about knowing in learning teaching, and research. One can conduct a longitudinal study covering multiple years in which the same group of students is interviewed multiple times.
Because of time limitations it is not possible in a Ph.D. thesis to conduct a longitudinal study to discover how graduate students’ ideas develop during the course of their graduate study. An alternative approach, the method adopted in this study, is to conduct a cross-sectional study.

Using this approach I interviewed a collection of graduate students once; the students were at different stages in their graduate career. Some of the subjects are first-year graduate students. All the first-year students were interviewed at the end of their first year when they were close to being done with their first-year coursework. Since they were still taking the core courses, they were able to reflect on the courses with these experiences fresh in their memory. Some of the graduate students I interviewed were close to finishing their Ph.D. study. They not only gave a clear picture of how graduate research is done, they were also able to provide some reflection on the courses from the perspective of how the courses prepared them for doing research. One of the interviewees had already finished the graduate program and was working as post-doctoral researcher. The rest of the graduate students varied from those who were just finishing the coursework at the end of their second year and starting to work with a research advisor, to those students who had been working with a research group for a while, but were still in the process of formulating their research topics.

Three out of fifteen interviewees were female. The overall number of female graduate students at the OSU physics department is so small, it is difficult to protect their privacy. Since this study is not about the gender differences, I have removed all references to gender identity completely, including giving everyone a male pseudonym.

Almost all the interviewees were domestic students rather than students coming from abroad to do their graduate study. Since I relied on my interviews to gather
information, the subject’s English communication ability is rather important to the study. Only one of the fifteen subjects was a non-native English speaker. Physics graduate programs have a larger proportion of international students and future studies could include more international students to obtain a more complete picture. The interview duration ran from 40 minutes to 90 minutes as appropriate to the interviewee. The interview time was scheduled at the interviewees’ convenience. The entire interview was audio taped and then transcribed. Each interviewee’s name was replaced with a pseudonym and any possible information that would lead to her/his identification was removed.

In order to get the professors’ perspective, one professor who had taught the graduate level core courses was interviewed. The professor was chosen because two of the graduate students had mentioned his course during the interview. From one of the student interviews, it was clear that this professor had done an outstanding job addressing the course goal of preparing students for future research. I also used the interview transcripts of three professors who taught quantum mechanics from another researcher in the field [93]. Their interviews also give the professors’ perspective on graduate core courses.

4.1.1 The Logic of the Interview Questions

There are four major parts to the interview. I started the interview with questions of general personal information. For example, how long they had been in graduate school, what courses they had taken, and/ or which research group they worked with. These questions served not only to gather basic information about the interviewees. They also served as light conversation to help the interviewees feel less nervous about
the interview. These are questions that have definite answers that help the subjects feel more comfortable talking while being audio-taped.

There were three core issues that I tried to examine in each interview. These were:

1. What does learning mean to you and how did/do you learn while taking classes?

2. How do you teach and why do you teach the way you do?

3. What does it mean to do research and how is your research experience so far?

To get a better portrait of what the graduate students think and what they actually do, I tried not to ask them any question as direct as what do learning, teaching, and research mean. Instead, I had them talk about the courses they took and how they studied for those courses. To help them to describe with specific examples, I asked them to compare a course they liked the most to a course they didn’t enjoy. I asked them what their approach to learning was for both courses and why they chose that approach.

To learn about teaching, I asked the graduate students what courses they had taught and how they taught the courses. Since all the graduate students had taught as teaching assistants, they didn’t really have full control of the courses they taught. During the interview, I went over how they taught and why they taught the way they did. After that, I asked them what they would have done differently if they had the freedom to teach the way they wanted to. I also asked them to describe how they would teach in the future if they were a professor teaching an introductory level course and a graduate level course.

It is interesting that all of the students were aware that they wouldn’t have the freedom to teach the way they would like to even if they were professors, specifically,
not at the beginning as a new faculty member. So I had to rephrase the question to ask them how would they teach if they were given the complete freedom to teach the course the way they wanted to.

To learn about research, it was easy to ask the higher-level graduate students to talk about their research because they had a clear idea of what they are doing. For students in their first two years, I could only ask them about what they thought doing research would be like and which field they planned to pursue. In the first few interviews, I noticed that most physics graduate students had had undergraduate research experience. Since their research experience as undergraduates seems to have had a critical effect on their beliefs about research, I included questions about their undergraduate research experience as well.

The set of interview questions may be found in Appendix A.

4.2 Overview of Participants

In this section I will present a general overview of all the interview subjects. None of the names are real. (See Table 4.1.) The column ‘year’ indicates which year of graduate study they are in. For example Gary had been studying in the physics graduate program for 3 years and 8 months at the time of interview. He was in his fourth year and so was labeled 4. One of the subjects, Oliver, had finished his studies with a Ph.D. degree. Several graduates had switched advisors during their graduate study. I included the number of switches in the table as well. I noticed a great number of graduate students had undergraduate research experience while I conducted the interview process. Under the ‘under research’ column, ‘N/A’ means
the undergraduate research was not discussed at all during the interview. ‘Yes’ and ‘No’ mean had or not had undergraduate research experience.

Other than the first-year graduate students, I asked all the students to talk about their research work in detail. Since it might be possible to identify individual students if their research fields are given, here I only label them as ‘experiment’, ‘theory’, and ‘computation’. For the same reason, to protect their privacy, I will block all information in the quotations that might be able to lead the reader to identify a student’s research field.

<table>
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<th>Name</th>
<th>Year</th>
<th>Field</th>
<th>U-grad. Res.</th>
<th>Additional Notes</th>
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<td>N/A (experiment)</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Charlie</td>
<td>1</td>
<td>N/A</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Darren</td>
<td>1</td>
<td>N/A (theory)</td>
<td>Yes</td>
<td></td>
</tr>
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<td>Frank</td>
<td>2</td>
<td>Theory</td>
<td>Yes</td>
<td>Master degree from other university.</td>
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<td>Lance</td>
<td>2</td>
<td>Experimental</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Allen</td>
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<td>Experimental</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Kevin</td>
<td>3</td>
<td>Experimental</td>
<td>Yes</td>
<td>Including one year from another university.</td>
</tr>
<tr>
<td>Gary</td>
<td>4</td>
<td>Theory</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Henry</td>
<td>4</td>
<td>Experimental</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Justin</td>
<td>4</td>
<td>Experimental</td>
<td>Yes</td>
<td>Master degree from other university.</td>
</tr>
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<td>Matt</td>
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<td>Experimental</td>
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<td>From a non-OSU university.</td>
</tr>
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<td>Nathan</td>
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<td>Experimental</td>
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<td>Ernest</td>
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<td>Experimental</td>
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<td>Taught high school for four years.</td>
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<tr>
<td>Irvin</td>
<td>6</td>
<td>Computation</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Oliver</td>
<td>Ph.D.</td>
<td>Theory</td>
<td>No</td>
<td>Graduated. Currently postdoc in a different subfield.</td>
</tr>
</tbody>
</table>

Table 4.1: List of interview participants and their basic background data.
4.3 Learning in the Classroom Setting

All the graduate students were required to take the core courses and a selection of advanced courses. They started their graduate work by taking courses to learn the physics knowledge they would need when they began to work on research at a later point. In this section I will talk about what their learning goals are, how they learned, and whether the courses prepared them for their future research.

4.3.1 Learning Goals

I’m interested in learning. It’s challenging and fun... — Lance

From the interviews, it is clear that physics graduate students chose to study physics because they are interested in physics. Many students said that they chose to study physics because they liked to be challenged and they were interested in doing scientific research in the future (A, B, C, L, I). The main reason physics graduate students chose to study physics is because they enjoyed learning it.

For this reason, physics graduate students all had the same primary learning goal for taking the courses, that is, to achieve the understanding of physics knowledge. But each of them had a different focus. Some focused on knowing the content knowledge and learning the problem-solving skills, some focused on obtaining techniques that could be used in their future research.

The conceptual ideas as well as problem-solving strategies. How to actually, you know, apply the theory to solving real problems and stuff. — Frank

The courses are about methodologies and techniques more than anything. I mean, the actual content knowledge, yeah, some of it I use, but a lot of it I don’t because it’s so broad and what we do as physicists tends to be very specialized. So the way I think about things, yes, that I use on a daily basis. You know, the way I think about things is something I
developed by taking all these courses. The actual, you know, facts, do I use every single one of them on a daily basis? No. I don’t think anyone does. — Justin

Here Frank focused on conceptual knowledge and problem solving while Justin focused more on the methodologies and techniques. Among the lower-level graduate students, Darren was the only interviewee who described learning techniques for future research as his primary learning goal when taking courses. Four of the lower-level students (B, C, F, K) had learning goals that were mainly focused on conceptual knowledge and problem solving.

Several students also mentioned that taking the courses is for students to learn the language of physics so they would be able to communicate with other physicists through writing/reading or discussion (A, D, H, J, N).

I think it basically gives everybody a standard knowledge base and language to start from, to, because in my perception a lot of research is dialog, and by that I mean, you know, anything from talking to someone in a casual conversation at a conference or in the hallway to, um, to writing a formal paper on a topic. All of those are part of that dialog that’s sharing information. So it’s hard to participate in that dialog if you don’t know the…the jargon, the specific technical language. — Henry

Understanding the language of physics enabled graduate students to communicate with other researchers. It also enabled them to learn from scientific materials in a non-course setting, such as reading journal papers and attending seminars. In this case, graduate students talked about learning the physics language from the courses in the way that it prepared them for future learning.

4.3.2 Preparation for Future Learning

I did [remember specific physics content] at the time. [laughs] But like everything you forget. My advisor even mentions things about he couldn’t
probably do a problem in Jackson if you asked him to. I think that’s true for everyone whether or not they would admit it. — Allen

When the advanced graduate students were asked how much they still remembered from the courses, they all agreed that they had forgotten most of what they had learned from the courses (A, F, H, I, J, K, L, M, N, O). Since the courses, especially the core courses, covered such a broad range of topics, the students argued that no one would be able to remember everything. Most of them admitted that they wouldn’t be able to solve any of the problems they had done in the courses just a few years after they took the courses.

To see the course goals physics graduate students perceived, I asked them to think about why they are required to take the core courses. Other than the historical reason of “because every physics graduate student has to go through it,” (A, I) there was a common response. Namely, core courses are to prepare students for all the possible research fields (E, H, L). Since every subfield requires a very different set of physics background knowledge, in order to prepare students for work in all the possible physics subfields in which they might conduct research in the future, the core courses have to cover a broad range of materials.

When I asked the upper level graduate students if they used any of what they learned from the core courses in their research, the common answer was very little if any.

Oh, My own research. Oh, nothing that’s directly applicable. — Allen

When I asked everyone, except those who were still taking core courses, how much they could remember from the core courses, everyone responded that they had forgotten most of what they learned unless it was something directly applicable to
their research. Even though none of them thought they would be able to solve a problem from the core courses, every one of them had the confidence that he/she could figure out how to solve a problem by reading the book and notes. Students thought that what was important was not how much they could remember, but that they would be able to find the resources and be able to learn or relearn anything they needed. Several of them were certain they could do it because they had re-learned some material when they needed it for their research.

And if there’s stuff I don’t remember off the top of my head I can review it and pick it up and I’ve done that. I mean, I do use it. I’m not a theorist, so I don’t use it on a daily basis, but, you know, there are times when I’ll have to go back and look at things. — Justin

This perspective agrees with using the concept of “preparation for future learning” to measure transfer. Bransford and Schwartz [13] have argued that it is less important to measure what knowledge students transfer out of their courses. Rather, the true signature of a successful education lies in a student’s ability to learn about new situations, using their prior learning experiences. In order to achieve that, instruction should focus more on learning how than learning what. Graduate students’ experience shows that students don’t retain the specific knowledge they have learned in the courses, but the act of taking courses prepared them to learn any physics knowledge they needed in the future.

4.3.3 Preparation for Future Research

Since graduate students are not expected to know how to do research when they first join the graduate program, it seems reasonable that graduate courses should prepare students to do research later on. So I asked the students who were working on a research project if the courses prepared them to do research.
The core courses particularly are very theoretical, “sit down and write out these solutions.” — Ernest

The general consensus was that the courses did not prepare one to do research.

You’re taught all these details in a book in the core courses, then you go to do research and you’re like, how do I actually do research? What do I actually do? Where do I look? You’re not taught any of those things. That’s not physics, that’s research. I didn’t gain any understanding of anything. — Nathan

There was strong consensus the courses didn’t teach research skills. Several students talked about why the courses didn’t prepare them to do research.

I’ve seen people who have not taken quantum mechanics or who have taken it so long ago that, you know, they haven’t used it and they’ve forgotten it, and they have no idea why that happens. And I’m not just talking students, I’m talking Profs. too. So, you know, is it vitally important? I guess not. You can still do research without knowing that, but at the same time, it’s nice to know. That comes out of having the basics down. You have to have the basics down. I think everyone does. It also allows for some sort of common language. You know, I can go to a talk on particle physics and yeah, I’m probably not going to understand everything but I’m definitely going to understand more than someone who never went though physics graduate school, just because there’s a common language there that we all share. — Justin

Three of them said that the core courses are there to prepare students for doing theoretical research (N, L, E). Lance also pointed out that students were not encouraged to pursue theoretical research unless they do well in the courses.

It seems that it is by consensus that if you’re going into experiment, the core classes aren’t nearly as useful. The professors see it as important to do, but not as important as the theory people see it. In fact, most people, if they’re not getting straight As, uh, seem to be discouraged from going into theory. — Lance
All experimental research students agreed that the best way to learn to do research is to learn by working with their advisor, other researchers, or students in the lab. With that in mind, several students still thought that the core courses should incorporate some experimental components. They thought this not only would keep experimental students interested in the courses, this would also help the theory students keep in mind that theoretical research is not completely disconnected from experimental development.

4.3.4 Constructing Physical Meaning

In quantum mechanics a lot of times, you might feel like we learned stuff that was just math. It’s applied math, but, you know, it was hard to see what was physically going on, you know. And because the graduate quantum mechanics tends to be taught by theorists a lot and, you know, I don’t think they’re really concerned with what something means physically, so, you know, I would take that into account when I would study, you know, and I wouldn’t think about what something meant physically, I would just try to get through the math. Learn how to operate with matrices and all that sort of thing. — Justin

When talking about the courses, almost all the students mentioned trying to understand the physical meaning of the course material. The lower level graduate students (first- to third-year students) said they liked the course more when the instructor tried to connect theory with real physical situations (B, C, D). Some extrinsically motivated students, (which means they were driven mainly by the grades), showed their interest in the material when the instructor included up-to-date research in the lecture (B, C).

Something other than the textbook, like, you know, the physics, or at least, you have to like, if you know the subject, you just wanna say something more than textbook because you’re in the field, you know more than the textbook. — Oliver
The upper-level graduate students (fourth-year and up) were able to talk about this in more detail. Some upper-level students pointed out that making connections to physical situations was a missing part of core courses (J, N, O). Justin said that he did not understand the physical meaning until when he need to apply the theory into his research. Two students suggested this was due to an over-emphasis on mathematical derivations (D, N). The result was that students got lost in the details and forgot about the real physical meaning behind the equations. The others thought that the lack of an experimental component in the core courses might have contributed to students’ difficulties in seeing the connections between physical situations and the problems they were solving (D, I, N).

There is not really an emphasis on the bigger picture: Why are you learning about a specific equation?” — Nathan

Researchers have shown that undergraduate students fail to view physics concepts as a coherent whole. Students in introductory physics classes tend to view physics as a mass of disconnected facts and struggle to transfer what they have learned in one topic into another related topic. Most physics graduate students understand that all the physics topics are related. Due to the structure of courses and the heavy loading on core courses, they struggle to look beyond the equations. This might also contribute to a troubling general trend I observed in the interviews: graduate students tended to lose motivation to learn in the core courses.

I like E&M in principle, but, um, in practice, it came off a bit dry and extremely dull and confusing and it was just tough to really get into. I like the idea of E&M, but actually doing it was no fun. — Irvin
Irvin failed to see how what he was doing in this course fitted into the bigger picture. Even though he was interested in the subject before, he lost the motivation to learn it in the course.

4.3.5 Course Load

Many students complained about the courses in terms of the course loading of their first two years of graduate study, especially how time-intensive the core courses were. Several students mentioned the pressure of getting homework done each week and not having enough time to achieve full understanding before the exams approached. Due to the stress on lacking of time, very few students pursued studies beyond the assigned material even when the instructors provide extra references.

Table 4.2 is a list of quotations of how students felt about core courses. The quotations are from different students and all of them had finished all the core courses. They described the core courses as boot camp that they are expected to pass to show that they are tough enough to face future difficulties.

Some students thought that the over-loading made them work harder and eventually they learned more. Others thought that they should have not put in so much effort on the courses but should have started working on their research earlier.

Physics graduate students want challenges in their learning. However, it appears from the interviews that unreasonable loading tends to make them lose some of their interest toward physics before they start working on research. Several students mentioned in the interview that they had lost their motivation toward physics and were thinking about leaving physics after they finish their degree.
<table>
<thead>
<tr>
<th>The basic courses, they were pretty much basic. There were definitely times that were very frustrating. — Henry</th>
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<tr>
<td>Because you’re so confused, you’re learning so many new facts, and you have all these different courses, and everything is jumbled, and you’re so bogged down, just learning the details is very hard. It is just too much for the student on their own, the average student anyway, to remember why are you doing this? — Nathan</td>
</tr>
<tr>
<td>I mean, the courses are, sort of, the way I see it, they’re sort of boot camp in a way. You go through and you get a practice at solving many different kinds of problems. — Ernest</td>
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<tr>
<td>In fact, one older graduate student, once said, you know, our theory right now is that the core classes are specifically just something everybody has to go through, just grind out, it’s like a rite of passage. It’s like passing through a gauntlet where all the professors bludgeon you over the head and once you get to the end, you’re part of the club. — Lance</td>
</tr>
<tr>
<td>Quantum mechanics, as you know, is not my favorite course because I was up till 2 or 3 o’clock in the morning on a weekly basis doing the homework sets and that never happened in statistical mechanics. — Justin</td>
</tr>
</tbody>
</table>

Table 4.2: A sampling of quotations of graduate students talking about the pressure of core courses.
4.3.6 Summary

The physics curriculum is focused on “you have thirty books to learn in the next four years worth of material, I’m downloading this information as fast as my ethernet connection can go from my brain to your brain.” That’s the point of the physics classroom lecture situation. It’s very efficient at simply transferring data because all you do is literally you put it on the board, they put it in their book, presumably they put it in their head. It’s just a transferring of data. — Nathan

Nathan’s analogy clearly illustrates a common teaching-learning model that graduate students perceived from taking the core courses: Namely the transmitting-receiving model. This instruction model may be the most efficient way of teaching, but from the students’ interviews, we can see that most students don’t retain what they have learned from the courses before they finish their degree.

Table 4.3 summarizes students’ views about knowledge in the classroom setting. The fact that most core courses are taught in a traditional format may contribute to the substantial number of graduate students who still believe that knowledge comes from external authorities.

Most of physics graduate level core courses are still taught in a standard format while a great portion of advanced courses have begun to incorporate some research-like activities such as research projects, presentations, or term papers. Students all agree that these activities take much more time and effort on the part of both the learners and instructors. Upper-level graduate students appreciated having a chance to learn and practice research skills in the classroom setting.

4.4 Teaching as Graduate Teaching Assistants

Because the professors don’t really know how to teach. It’s easier to teach because it’s a smaller class in the grad level courses. It’s easier because it’s closer, hopefully, to the material that they’re more familiar
<table>
<thead>
<tr>
<th>Name</th>
<th>Year</th>
<th>View of knowledge</th>
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<tbody>
<tr>
<td>Brian</td>
<td>1</td>
<td>Absolute</td>
</tr>
<tr>
<td>Charlie</td>
<td>1</td>
<td>Absolute</td>
</tr>
<tr>
<td>Darren</td>
<td>1</td>
<td>Contextual</td>
</tr>
<tr>
<td>Frank</td>
<td>2</td>
<td>Absolute</td>
</tr>
<tr>
<td>Lance</td>
<td>2</td>
<td>Contextual</td>
</tr>
<tr>
<td>Allen</td>
<td>3</td>
<td>Contextual</td>
</tr>
<tr>
<td>Kevin</td>
<td>3</td>
<td>Contextual</td>
</tr>
<tr>
<td>Gary</td>
<td>4</td>
<td>Absolute</td>
</tr>
<tr>
<td>Henry</td>
<td>4</td>
<td>Contextual</td>
</tr>
<tr>
<td>Justin</td>
<td>4</td>
<td>Uncodable</td>
</tr>
<tr>
<td>Matt</td>
<td>5</td>
<td>Absolute</td>
</tr>
<tr>
<td>Nathan</td>
<td>5</td>
<td>Contextual</td>
</tr>
<tr>
<td>Ernest</td>
<td>6</td>
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</tr>
<tr>
<td>Irvin</td>
<td>6</td>
<td>Absolute</td>
</tr>
<tr>
<td>Oliver</td>
<td>Ph.D.</td>
<td>Uncodable</td>
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Table 4.3: Graduate students’ view of knowledge in the classroom setting.

with. Still...But in the end, it is the same caveat, we’re not teaching people how to teach before we throw them into a classroom. So whether that’s me as a graduate student, being a TA, or a professor, as a researcher, being a professor of a course, in general we are not taught to teach. — Henry

Most graduate students don’t have much teaching experience when they first come to the physics graduate program. Among the students I interviewed, only one student had real prior teaching experience. This person taught high school physics for four years before he started the graduate program. The rest of students felt that they had to figure out how to teach while they are doing it.

In the OSU physics department, all the graduate students teach as teaching assistants. Here there are a great number of undergraduate students taking introductory physics classes. Most graduate students teach recitation or lab for the introductory physics courses. The advantage of this arrangement is, for the inexperienced TAs, the
materials for teaching are all prepared. All they need to do is to review the material before they go in to teach. Other than some very rare cases, graduate students never need to plan a class from scratch.

Generally, introductory physics courses have one lead instructor, who prepares the syllabus and the weekly schedule for the entire quarter. All graduate TAs are required to participate the weekly meeting. Instructors and recitation TAs go over the material for that week and discuss all the issues of the course. Labs generally are run by a separate instructor. The lab TAs meet one per week to make sure they are familiar with the lab set-up as well.

4.4.1 Teaching Experience

There it was just sort of a, you know, I went in, solved problems for them and left. I had no real control so it was sort of frustrating from my point. I was just a robot sent in to, you know, sort of keep these guys in line for an hour and then turn them loose. — Irvin

The reality of the constraints that courses run efficiently and effectively is that TAs have little freedom to innovate as teachers. Graduate students felt that they had little control over the class when they taught as teaching assistants. Some of them didn’t think they are teaching, because all they did in recitation were solving problems for students. (B, H, I) Another common comment is that there is a disconnection among lecture, recitation, and lab. Graduate teaching assistants thought that there should be better integration of the course.

Irvin talked about how he would like to rearrange the student groups to make them work better, but he was not allowed to do so.

Because inevitably you either get a group that none of them know what they are doing or all of them know what they are doing, or there’s these one or two groups where there’s one guy in the group that knows
how to do all of it and they all fall back on that guy. If I had any control I could sort of disperse those groups. Put the people that didn’t know what was going on with the people that did and sort of even things out, but I wasn’t allowed any control over the groups and so... — Irvin

Justin talked trying to get students work in groups.

I tried to get my students to work in groups because I think that that’s a much better way to learn because it’s an active form of learning versus a passive, you know, me lecturing at the board, and eventually I realized that that was not feasible because there’s too much material to cover and I couldn’t get through it all with them working in groups and the students didn’t like it. — Justin

I told [the lecturer] what I was doing, he seemed, you know, okay with it, just make sure that you get through it all, and because I didn’t think I was getting through enough of the material, I stopped doing it. That, and the students were complaining. I gave them what they wanted and unfortunately in my opinion it was to their detriment. They are not picking things up as well as they possibly could. — Justin

Both Irvin and Justin were able to make good judgments about how to help their students learn better. Unfortunately, either the lecturer didn’t allow the change, or the lecturer declined to reduce the amount of material that was to be covered. In both cases, they had to give up what they believed would be better for the students and teach the way they were told.

Now one thing I’ve learned is that you can teach as bad as you want as long as you don’t cause the lecturer or professor any trouble. As long as you stay quiet, you can do the bare minimum. You can do as much as you want, you can be doing a great job, but if you cause the... this is only in some of the cases, if you cause some of the lecturers or some of the professors to have to do any extra work, they will be on you, like they will be on your back for the rest of the quarter for causing a scene. So what seems like most of the TAs do is and I’ve heard them say something akin to the phrase: Just do exactly what they tell you, don’t do anything extra, just stay off the radar and you’ll be fine. So where’s the motivation to be a good teacher? — Lance
Lance mentioned that it was better do the bare minimum than try to do a good job with teaching. Overall, graduate students have little motivation to teach due to the teaching environment. They taught in a set curriculum with pre-determined discussion problems and homework questions with which they helped students. They were not directly invested in the learning processes of the students. As motivational studies have shown, the default position in such constrained systems is that TAs end up doing the minimum necessary to get by. More importantly, the experience of being a TA may limit the possible teaching models that the TA is exposed to. Simply put, if you have not experienced any alternative teaching models, you have no model that you can access in the future when you are in charge of the course. The default position is that they will stick to what they are familiar with. This probably contributes to Black and Wiliam’s [6] observation that it is very difficult for systemic change to happen.

4.4.2 Future Teaching

When I asked the students how they would teach in the future when they became professors, most of them answered that they would teach the same way they were taught (11 out of the 12 who were asked to answer this question.) One possible reason is they don’t know any other way to teach. Another possible reason is that they think there are some constraints on how they could teach in the future. Students mentioned that there are departmental constraints. For example, the department they would be teaching in, in the future, might require them to teach in a certain way, with a particular textbook, or with a list of topics to cover (8 out of 12). The other
constraints included the possibility that the professor might not have enough time to cover all the material since the alternative teaching format might take more time.

What’s more interesting is that when students talked about teaching the introductory level physics, all of them agreed that they should take a more interactive approach, but for the graduate level courses, they all thought that the teaching should stick with the lecture-only format. They did have very different reasons for this. Some argued that the graduate students were, by nature, active learners, and therefore it was okay to have the passive lecture format graduate level courses. Some thought that the graduate materials were so difficult that students would not make any progress in group work. Some thought that in order to be able to cover so much material in the limited time, the lecture is the best way to get through it all. Despite my attempts to ask the graduate students to visualize an ideal world in which they were permitted to teach in any way they wanted, there were only two students willing to overlook the possible obstacles. Both said that they would have to investigate and learn more about alternative teaching methods before they try them.

I think there are two possible reasons that make them have very different reactions to teaching the introductory physics and graduate level courses. One is because they know the introductory level physics materials better, they know what it takes to help students achieve better understanding. For the graduate level courses, on the other hand, they barely understand the material, little enough that they don’t have the full confidence to teach the materials in an uncertain way. The other reason is that they have very different experiences with these two groups of courses. In OSU physics, one of the introductory physics courses is taught with physics education research influenced materials. In this course, recitations are run in a group discussion format.
Several of the graduate students had experience in teaching this particular course and the others also had some experience in using group work for some other courses. They had seen the benefit of teaching with physics education research-based curricula and interactive engagement methods in the introductory level, so they supported the idea of teaching the introductory courses in a more interactive way. On the other hand, most of the graduate students had only seen the graduate level courses being taught with the traditional lecture format. Not having first-hand experience with alternative instruction methods at this level, in addition to lacking full confidence in their understanding of the material probably made them uncomfortable with the idea of adopting new methods.

4.4.3 Summary

If I’m the professor, and then it’s very advanced courses, some interesting research in the future, then I may give them some [term paper]. I may think about it. I’m not so sure, but yeah, it also takes the time, my time as well right? It’s also good for students, but... Maybe as I teach, as I spend time with them I can also learn from the students as well in the process, so, so it also depends, yeah on my motivation. — Oliver

Teaching and learning are closely related to one another. In the process of teaching, a teacher not only learns the material he/she is teaching better, he/she also gains experience in teaching. Good teaching approaches take the teacher greater effort and time to prepare and to teach. Without the motivation to teach for learning, it is hard to imagine many faculty members would be willing to invest time and effort from their already busy schedule.
Future physics faculty come from current physics graduate students. Unfortunately, the current preparation of physics graduate students for future teaching appears inadequate. Not only is their teaching experience mostly limited to the introductory level courses, also they are teaching as teaching assistants — they don’t have any chance to practice how to put a course together. In the following excerpt, Lance suggested that graduate teaching assistants should have more freedom in their teaching.

I would pretty much insist on more autonomy for the teaching assistants. I found it a lot better and a lot easier to teach for the professors who considered their TAs to actually have intelligence of some amount. When the professor or the lecturer comes in and in my experience it has almost always been the lecturer who comes in with the attitude that the TAs are dumb and you’re going to do it exactly how I show you, and no other way, and you’re basically my remote control. The TAs don’t care as much, they just do what they are told. They don’t try any extra and the students aren’t dumb, they feed off of that, they just do the bare minimum too. — Lance

Letting teaching assistants have some autonomy on teaching not only could give them a chance to evaluate their own teaching and to try out different teaching approaches, it also might keep them motivated to teach better.

4.5 Learning to Become a Researcher

Graduate students all agree on no one can get a Ph.D. without doing research. Being able to conduct research is the critical requirement for anyone who wants to receive a Ph.D. degree. Accordingly, the primary goal of the physics graduate program is to prepare a graduate student to become a physicist, a researcher who does physics research.
In the initial stages of my research I gave a survey to 27 graduate teaching assistants in the OSU physics department. One of the questions I asked was, “What do you expect to get from your graduate study?” The survey was in free response format (no possible options were suggested to the students) and the summary of the answers is provided in Fig. 4.1. Most students gave more than one answer. Of all responses, 48% mentioned “to achieve a better understanding of physics,” 48% mentioned “to learn the skills of doing research.” By comparison, fewer than 20% of the teaching assistants said that they wanted to learn how to teach.

It is clear that research is a very important part of a students’ graduate career. This is the time they learn and practice to become a researcher. Students consider this to be the very reason that they pursue graduate study.

Figure 4.1: Response on the question “What do you expect to get from your graduate study?” from graduate teaching assistants. (n=27)
Because the 15 graduate students I interviewed in detail varied from first year to students who had gotten their degree, they were in different stages of their research. This part of interview focused more on undergraduate research experience if they had not yet started working with research group. The discussions vary from subject to subject.

4.5.1 Undergraduate Research Experience

Almost all the graduate students had some sort of research experience before they started their graduate study. Only two out of eleven students that I questioned in detail had had no research experience as an undergraduate. (The others were not asked about undergraduate research.) In Hunter’s study, she showed that there exists a strong correlation between students who participate in research experience in undergraduate (REU) and those who pursue graduate study [80]. She warned that the results shouldn’t be interpreted in such a way that research experience makes students more likely to pursue graduate study. She suggested the correlation might be there because students who plan to attend graduate school generally try to get some research experience to put on their resume.

Since all my subjects were graduate students already, I asked them why they chose to participate in research as an undergraduate and if their research experiences had any influence on their decision to embark on graduate study. Those who were asked this question all responded that they decided to go to graduate school before they participated in research. One of the students said that he had had such a bad undergraduate research experience that it gave him second thoughts about going to graduate school. He even took off a year from school after receiving his bachelor’s
degree to figure out whether graduate school was what he wanted. These responses agree with Hunter’s reasoning. Undergraduate students who have planned to attend graduate study are more likely to participate in some research project. Some bad undergraduate research experiences may lead students to question their decision. On the other hand, good undergraduate research experiences can develop undergraduate students into confident and able researchers by the time they enter graduate school.

The graduate students I interviewed had had various research experiences. Two of them were working on the same research projects for three and four years. These two students really had a clear picture of what to expect from doing research and were both very motivated towards doing research. I will discuss one positive undergraduate research experience in detail in Chapter 5. Three students attended the official REU program funded by the National Science Foundation (NSF) [77]. These students conducted full-time research at a different university for a summer. Some students’ research experience was part of their undergraduate program requirement. One of student’s research experiences was turned into his thesis for a masters degree.

Several students had more than one research experience. They were able to talk about differences between each research project and what they gained from participating in each. Several students had negative experiences from doing a research project. Those negative experiences seem to have done some harm to their motivation toward research.

The positive research experiences have some common identifiable characteristics. In each case, students were expected to be independent researchers, their ideas were valued and they were required to make their own decisions in their research project. These students also mentioned that they learned that sometimes experiments fail.
This experience made them have less fear about making mistakes and helped them to gain a sense of autonomy in doing research. Students who had positive research experiences all have positive attitudes toward their future or current research.

The negative research experience students talked about “having bad luck” in collecting data, or a disorganized research project in which nothing got done. One student, Charlie, talked about how he went through a well-organized research project and a REU summer program without learning anything. He described his research experience as,

I mean, the instructions, like, were pretty clear. I didn’t have to figure out what I was supposed to do.” — Charlie

I asked him if he gained more understanding of the field or have more interested in doing research

Does it make me more interested [in physics research]? Not really. . . But as far as helping me to understand some are of research, it didn’t. Like I barely learned anything from that.

He also mentioned some other graduate students had similar research experiences that shows that this is not a unique case. This agrees with Hunter’s finding. What’s important is not how many projects or how long the research project was that students participated in. What is important is what they do while they are doing the research. Here we can see Charlie didn’t learn much from doing the research by following clear step-by-step instructions. The research experiences didn’t make him more interested in physics either.

4.5.2 Doing Research

During the interview, all the upper-level graduate students were asked to describe their research. Two of the students were able to articulate their research projects in
detail. Here I will use the analysis of their transcript to show how physics graduate students are able to apply specific aspects of an identifiable scientific method in their research.

The Investigative Science Learning Environment (ISLE) is an instructional innovation that help students learn physics in a way that is similar to the discovery process that physicists use to develop their knowledge. The ISLE cycle was designed based on the activities physicists engage when doing research. ISLE is also informed by cognitive studies and the history of science [27]. The ISLE cycle demonstrates the methods and strategies that physicists adopt in authentic research activities. The ISLE cycle runs with the following sequence of:

1. Conducting systematic observation,

2. Generating multiple hypotheses,

3. Making predictions of the outcome of a possible testing experiment, based on a hypothesis, including necessary assumptions,

4. Conducting testing experiment and comparing the outcome of the experiment with the prediction,

5. Evaluating the result and making appropriate revisions to one’s hypotheses, assumptions, and/or experimental design.

In these two students’ description of research, it is clear that they were using similar research strategies in their research (See table in Appendix B). They were able to synthesize the past research results to present their current research questions,
propose one or more possible hypotheses, design a testing experiment with consideration for controlling systematic uncertainties, and make a prediction based on the identified hypotheses, including assumptions. One of them even identified alternative hypotheses and provided the relevant predictions. This analysis suggests that they were conducting authentic scientific research. Not only they were able to articulate the entire research design, they were also able to relate their research questions to a bigger picture of understanding the fundamental physics. Clearly, they were intrinsically motivated toward their research projects.

4.5.3 Learning to do Research

So where did graduate students learn how to do research if they didn’t learn it from the courses? All of them answered that you learn to do research by doing it. Several of them stated that’s the best way to learn to do research (A, B, D, E, H, J, L, N).

Ernest was the only one who was involved with writing research proposals. Although the proposal he had written was not accepted, he had gained a valuable experience. But for him, that’s not enough. In his research, he cooperated with research groups in other universities. In the interview, he talked about how he wished that he had the experience that the students at the other university had.

Typically, for a given experiment, there’s often a thesis involved by someone: a student somewhere. Most of the students at [that university] are involved with the process the whole way through. So they’re involved with writing the proposal. They become the primary spokesperson for the experiment, in charge of running the experiment, and then they do the analysis for their experiment. So, I’ve not done all those steps, but I’ve also worked on a lot of different experiments. — Ernest
Here Ernest talked about how those students in another university had the chance to take the lead on a complete research project. In the process, students learned all the valuable aspects of doing research: putting together a proposal, making decisions on the experiment, analyzing the data, and presenting the results. The students were treated as researchers in that they took charge of the entire project. There can be no doubt that such students have more chance to transition from a student to a researcher.

Another important research skill students should have is the ability to evaluate, which includes evaluating their own and other people’s work. Allen suggested having a research course for students to work on some research projects as early as the first year. In this course, students would grade each other so that they could learn how to evaluate each other’s work.

They will have to learn this eventually. So why not start up first year. So they might not know how to judge this research, but if they talk about it, and maybe even grade the grading, have the reviewers, have the faculty look over some of the reviews and say, ‘look he is not, this student, he or she is not expected to know this at this point why do you criticizing him on this?’ And something like that. I dunno, it might help them know or, it’s uh. ‘I like your point here about how you said the student should have gone further in this direction or wasn’t paying attention to this whatever, it’s very good, you should keep an eye out for this.’ Allen

He agreed that students would not know how to evaluate at first, so he suggested providing scaffolding and feedback to help them learn while doing it.

4.5.4 Summary for Research

From the interviews, some of the students clearly demonstrated that they had acquired the skills they needed to conduct physics research. Some of the students also pointed out that they needed to have practice with proposal writing, taking charge
of the research project, and evaluating research results. There are few structured venues in the physics department where students can practice these activities. Often, students have to rely on their advisor to give them such opportunities to practice in the research environment. Naturally, the quality of such learning experiences will vary from advisor to advisor. The development of self-authorship amongst the graduate students is summarized in Table 4.4.

<table>
<thead>
<tr>
<th>Name</th>
<th>Year</th>
<th>Developed self-authorship?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brian</td>
<td>1</td>
<td>Yes</td>
</tr>
<tr>
<td>Charlie</td>
<td>1</td>
<td>No</td>
</tr>
<tr>
<td>Darren</td>
<td>1</td>
<td>Yes</td>
</tr>
<tr>
<td>Frank</td>
<td>2</td>
<td>No</td>
</tr>
<tr>
<td>Lance</td>
<td>2</td>
<td>Yes</td>
</tr>
<tr>
<td>Allen</td>
<td>3</td>
<td>Yes</td>
</tr>
<tr>
<td>Kevin</td>
<td>3</td>
<td>Yes</td>
</tr>
<tr>
<td>Gary</td>
<td>4</td>
<td>Yes</td>
</tr>
<tr>
<td>Henry</td>
<td>4</td>
<td>Yes</td>
</tr>
<tr>
<td>Justin</td>
<td>4</td>
<td>Yes</td>
</tr>
<tr>
<td>Matt</td>
<td>5</td>
<td>Yes</td>
</tr>
<tr>
<td>Nathan</td>
<td>5</td>
<td>Yes</td>
</tr>
<tr>
<td>Ernest</td>
<td>6</td>
<td>No</td>
</tr>
<tr>
<td>Irvin</td>
<td>6</td>
<td>No</td>
</tr>
<tr>
<td>Oliver</td>
<td>Ph.D.</td>
<td>No</td>
</tr>
</tbody>
</table>

Table 4.4: An assessment of student autonomy in research.

How do graduate students transition from students to researchers? From the interviews, it is clear that the structure of the research environment is important in facilitating this transition. However, a good research environment is not sufficient to guarantee this transition. I will illustrate the complexity of this issue with a pair of in-depth case studies in Chapter 5.
4.6 Overall Summary

During the interview, one of the graduate students said that research for graduate physics program is like lab for introductory physics class. It has been suggested that students learn the physics better if the introductory physics class has coherent incorporation of the lab, recitation, and lecture [27]. If the research is the lab part of graduate program, the program should try to make more connection between the courses and research. Students were able to identify indirect ways in which the courses prepared them for their future research (e.g., learning the language of physics, learning the way of thinking). Unfortunately, from the interview data, students seem to feel that the courses are completely detached from the later research. Not only did the students fail to learn research skills while taking courses, some of them lost their interest in physics while going through the courses. From graduate students’ teaching experiences, it is questionable whether they are prepared to be a lead instructor to put together a course and teach by themselves. What’s worse is that several lost their motivation to teach or to learn how to teach better because of their experience of teaching as teaching assistants.

Physics graduate students come in to the graduate program with the interests of learning physics and conducting physics research. If they become the future faculty, teaching would be one of the major parts of their career as well. Currently most graduate students don’t seem to see the connection between learning in courses, teaching, and doing research. Some of them also lost their interest in teaching, learning, or research. There are some interesting connections between learning, teaching, and research I observed in individual interviews. I will present them in the next chapter.
to further illustrate how graduate students motivated to learn, to teach, and to do research based on the environment they perceived and their beliefs about knowing.
CHAPTER 5

CASE STUDIES

During the process of the interviews, I discovered more than I was expecting to find. The graduate students’ interviews gave me insight into how graduate students are thinking about their learning in the graduate program. Due to the size of study, it is not possible to answer questions about what percentage of the student population these cases represent. At the same time, the limitations of the number does not mean these case studies are not important. These cases show us two things. First, case studies reveal the existence of certain phenomena in our physics graduate student population. Second, the detailed information gathered from the interviews gives deep insight into the mechanisms of students’ cognition and meta-cognitive behavior. Even if the case only happens to one single student, it still provides information about the mechanism of what is going on in students’ heads. Understanding the mechanism through which epistemological beliefs affect graduate students’ approaches to learning, teaching, and research will help us better understand how this complex dynamic system functions. Such understanding of mechanism may, in turn, lead to principled ideas about how we can change the graduate physics program to support the learning goals of better training physics graduate students to become future researchers.
5.1 Case Study 1 — The Interaction of Course Goals and Students’ Learning Goals

Each instructor who teaches a course will have some course goals in mind. Even if those goals are not explicitly written or stated, instructors normally have some idea of what they are going to teach and what they want their students to learn from the course. Unfortunately, research has shown that the course goals that students perceive are not always the same as what the instructors have in mind [84, 94].

Charlie and Darren were two physics graduate students from the same year. I interviewed both of them in the very last week of their first year. They took two of the same core courses, statistical mechanics and quantum mechanics, that year. I didn’t choose them for the comparison. Only after both of their interviews did I realize that their different descriptions of the same two courses give a clear contrast of how different the students’ views could be for the same courses. Charlie and Darren had very different learning goals when they approached their learning for the core courses. In addition, the two courses happened to be taught with very different styles by their respective lecturers. The contrast between the goals of these two courses will demonstrate how students adjust their learning approaches in different learning environments.

5.1.1 Course Goals

The two courses I am going to discuss here are statistics mechanics (stat. mech.) and quantum mechanics (quantum). All the graduate students at the OSU physics department are required to pass the four core courses by the end of their third year. Stat. mech. and quantum are two of the core courses. The other two are classical
mechanics (classical) and electromagnetism (E&M). There are two quarters of stat. mech. and three quarters of quantum.

The two professors who taught these two core courses were both experienced instructors. The professor who taught quantum had taught the same course several times before. The professor who taught stat. mech. had taught several graduate level and upper level undergraduate physics courses, but this was the first time he taught the graduate level statistical mechanics. Both instructors were successful researchers who conducted research somewhat related to the courses they were teaching.

Quantum Mechanics

The quantum course was taught like a regular core course. Most of the class time was devoted to lecture. Each week, several end-of-chapter problems were assigned as homework. The problems on the tests were similar to the homework problems. The most unique element of the quantum course was the quiz. Each week, the professor gave a quiz. The exact question on the quiz was given two days before the quiz day, and the students would have five minutes in class to complete it. The quiz questions were mostly derivations or some calculation related to that week’s material. From interviews with several graduate students, the reaction to the quizzes was extremely polarized: Students either really liked the quizzes or hated it very much.

Statistical Mechanics

After interviewing Darren, I realized that the stat. mech. course that year was taught in a format that was rather different from the other physics core courses. Because of this, I decided to interview the professor who taught that course to find out what were the professor’s course goals. I will call the professor Prof. S.
I asked Prof. S what he wanted the students to learn from his course. He replied,

What I would like to do is to show to them how the techniques and the concepts that they are learning in this course would be of use to them more or less irrespective of what they would do in the future.

Prof. S talked about physics graduate students having a variety of job options in the future. Because of that, he wanted to show them what they were learning in the class could be useful in various physics subfields. This idea is similar the concept of preparation for future learning [13].

I try to keep in mind that my students not only come from varying backgrounds, but more importantly will go on to do very different things in the future. You know, some of them might be theorists, others might be experimentalists, some of them might go into astrophysics, nuclear physics, high energy physics, condensed matter physics; experiment or theory. So what I would like to do is to show to them how the techniques and the concepts that they are learning in this course would be of use to them more or less irrespective of what they would do in the future.

When I asked him what the most important thing he would like his students to get out of his class was, he answered,

So it’s just trying to communicate, you know, to [the students] that this is important subject matter that they must master and not because it has been historically important; certainly that too because that gives them a feeling for, you know, big achievements in physics and so on, but also that it’s not a dead field, it’s something that can actually be used right now and will be used by them in the future. And so it’s in their interest to really learn it well.

Since most physics core courses cover historical physics ideas that are no longer focal points of research, and core course materials have been around for decades with only minor additions and alterations, a question that every instructor must face is: How is it possible to present the subject as something of real applicable value
to current/future research and consequently how do I keep students interested and motivated?

Prof. S provided a remarkably unique perspective on this problem. When the professor talked how he would expect students to work on the homework, we can see his idea of teaching and learning.

I think one can ask far more challenging problems in the homework, there’s no time constraint and indeed I know that some of them do it together, and that’s fine with me. Because actually in trying to explain something to your friends, you learn something, and sometimes you also learn better if your friends are trying to explain it to you than if a teacher is trying to because you can stop them, you can pester them, saying, no that’s just completely wrong and then you can have a discussion and so on and so forth. So I think all of that is something that I wanted to encourage.

Here, he illustrated the idea of learner-centered learning. That the homework is not only for students to practice what they have learned in class, homework was used to encourage students to work with each other. Working together is not for them to help each other get the correct answer, but for them to practice explaining their own ideas and evaluating other people’s explanations as well. He also pointed out that students are more likely to stop another student when they think he/she is wrong than to stop a teacher during lecture. Later I will use a quotation from one of the students to show how Professor S. designed the homework to encourage student discussion.

The professor also has very different emphasis on problem solving and evaluation of students’ problem-solving performance. Here he is speaking about his approach to exams:

I used to tell them is, if you’re doing a problem, always check at the end of the day whether your answer is dimensionally correct. You always have
recourse to things like dimensional analysis — always do that! Even if you run out of time, even if you write there, “hey, this is where I reached,” but when I do dimensional analysis, my answer is clearly wrong, that itself may earn you points in an exam. But in fact in real life, that will be your pointer to the fact that you have made an error and that you have to go and do it again, and that’s it. Here you ran out of time. So do things like that is what I was trying to say. Or, you know, if you do a calculation, if you get an absurd answer, you should be able to see that I’ve got an absurd answer and I must have made a mistake somewhere.

He clearly told his students that what is most important is not getting the correct answer, but being able to point it out when and where it is wrong. The reason it is important is because that is what they need to do in real life when no one can tell them whether they have got the it right. He tried to deliver this message through how he graded the exams. Overall, professor S. would like his class to understand that what they are learning is useful for their future career. They should learn through working with other students, and should able to evaluate their own or other people’s ideas. He would like them to learn to think with statistical mechanics like a physicist.

I believe many physics professors share Prof. S’s course goals, i.e., to prepare graduate students for the future research and a variety of possible jobs. However, research at the undergraduate level has shown that most of the professors are not able to achieve their goals due to the departmental constraints (like choice of textbook, class size...) and/or lack of experience and knowledge about teaching and learning [74, 1, 95, 96]. Here Prof. S showed a possible model of teaching higher level skills in the physics graduate level core courses. He not only taught those ideas in the lecture, he also designed the homework and test questions around the same ideas to encourage students to learn to think like researchers. Later, from Darren’s interview,
we will see more about how the stat. mech. was taught and how Darren was learning in this course.

5.1.2 Charlie

Charlie was a first-year graduate student who was interested in experimental physics. He would be considered a good student who studied hard in all the courses and achieved average or better grades in all the courses he took.

Learning Goals

I asked Charlie what he tried to get out of the core courses. He answered that he would like to achieve a mastery of the subject without a clear idea what that actually meant or what that mastery might be good for.

Like a mastery of the subject would be nice, but like, what I’ll use that for, I don’t really know. Hopefully, you know, I’ll use it to maybe teach it to other students later in my career, but, um, like other than that I couldn’t say specifically what I would use.

Charlie knew that he has to learn something from taking courses, but he had no idea how he could use what he learned from the courses. The only possible use of that knowledge he could think of was to teach it to the students in the future. Without a specific goal for learning, Charlie was motivated extrinsically by the grades to keep on studying for the courses. For example, in talking about how the quantum quiz helped him learn he said:

Like I didn’t really understand the notes and like, you know, it’s all laid out in the book, but just staring at it for a couple of hours and knowing that there was a quiz on it definitely helped me. And it’s a pretty simple derivation. It’s only a few steps, so, having to do that for a quiz definitely forced me to learn it.
Perceived Course Goals

When I asked Charlie what the important things that students learn from the courses like quantum mechanics are, he started to name each of the topics covered in quantum mechanics. The course goals he perceived were completely focused on the content of the courses.

So I asked him if anything he learned in the core courses might be useful for his future research. He answered,

I don’t know how helpful classical is, but, like, I think it’s an important thing to learn if you’re a physicist. You just have to learn classical mechanics whether you use it or not. I haven’t taken E&M yet, but that probably is a good course for, like, mastering certain fields of mathematics, but, like, I’ve heard, I’ve heard people say it’s not really useful in their research... I can’t foresee it being very useful.

Clearly he thought that what he learned would be useful in the future only when the content knowledge would be directly applied to the research.

Because Charlie wasn’t able to say clearly how he might use what he was learning in the courses in the future, I asked him if he had found anything interesting so far. He replied,

Some of the stuff we covered in stat. mech. was pretty interesting. Like in the second quarter of the stat. mech. we actually get into using stat. mech. to do some modern physics problems. I found that interesting for a while. And it ended up being pretty confusing about half way through the quarter. So obviously when it gets too confusing, it is not very interesting any more. Up to about midway through second quarter I was interested in that class. Quantum, the whole thing has been, I found the whole thing pretty interesting. Sometimes it is slow and boring, and it doesn’t seem like the lecturer is very interested. No one seems very interested.
Charlie found the course interesting when he saw the connection between the material and real world physics. It seems that most of the time, he didn’t find the courses interesting, even including his favorite subject, quantum mechanics.

**Learning Approach**

How did Charlie study for the courses?

I oftentimes found that in doing the homework it is better to find worked out solutions first. And I found that to be pretty common strategy among the other students.

When he worked on the homework, he preferred to find worked out solutions first. His learning was directed towards studying the solution.

One unique feature of this quantum course was that there were quizzes every week. Students received the question two days before the quiz. Then they were given five minutes to answer the exact question in class. Charlie talked about how the quizzes helped him learn the most and how he studied for the quizzes.

I sit down, I read it, um, in the book, and I read [Prof. Q’s] version of it from his notes and I, like I copy it basically. I write it down in the notebook several times, and, um, you know, I do that without looking at the notes or book to make sure I can do it.

Usually by Wednesday [the quiz is] up. So we have at least two days to work on it. And it is very effective studying, like, we all get together in someone’s office, like you’ll find two or three groups on the third floor, with a bunch of different first-years and second-years, working on this quiz problem, and I think that’s very effective studying and you do, like you master that particular problem, but maybe...I sometimes think it’s a little too focused, like you are too much on that problem, and even though it’s very basic and very important, um, you don’t spend as much time studying the general topics.

This approach is similar to how he worked on the homework. For Charlie, learning involved repeatedly studying the same material and repeatedly doing the same
problem. His learning was focused on studying the solution in order to know it well enough to do it at the five minutes quiz. His goal of learning is to know the problem solving procedure well enough to do well in any of the tests. During the interview, he mentioned the time pressure issue of taking the courses. For him, efficiency was an important factor that guided his choice of study strategy.

I asked Charlie how well he learned from the courses. His answer gives us some idea of what he thought learning meant.

I think I know it pretty well and if I retook the courses I would probably do much better. Like I’ve... I would say I have mastered like the basics of it, um, but, that’s as much as I can say.

He used the world “master” or “mastery” several times during the interview. But what he actually meant was “know” and “remember”. He said that if he takes the same course again he would do much better. That implies he equated familiarity with understanding.

5.1.3 Darren

Among the graduate students I interviewed, Darren was unusual because of his ability to articulate verbally what his learning goals were and how he approached learning while he was taking the courses.

Darren had a very clear goal for his graduate study, namely he would like to do research on theoretical physics in the future and he expected that the courses he took should prepare him for that career. He was interviewed right after the last final exam of his first year. During his first year, he took quantum mechanics, statistical mechanics, and classical mechanics.
Darren was really open to talking about his graduate experience. During the interview, when I asked one simple question, he would give more information than what I asked for. Sometimes, he talked about things before I even asked about them. What he talked about were mostly his own ideas, which were elicited without much probing at all.

**Learning Goals: Preparation for Future Research**

Darren’s learning goals were oriented toward preparing himself for future research. He didn’t view preparation for future research as an unreachable ideal goal. He actually thought it through and has a clear idea on what he needed to do to achieve it.

Once you’re here, the main interest is, can you succeed in research? Well, and I think that there should be some interest in can you succeed as a teacher, because a lot of us are going to become teachers, and I think that there is a lack of interest in that. But I think that the core courses ideally should be establishing: can you succeed as a researcher.

When I asked him what he meant by knowledge for future research, he replied,

Well, definitely not knowledge in the sense of just learning what’s out of the book. Memorizing the book is not knowledge that’s necessary, but knowing techniques, knowing good ways to proceed in a theoretical field. Knowing to ask for help. Knowing to work with others. That kind of thing.

Darren focused his learning on the process of doing physics research rather than the physics content. In Chapter 2, I showed that one of the most important learning goals for transfer should be *preparation for future learning* (*PFL*). Here, Darren’s learning goals are similar to the PFL concept and specifically directed toward future research. Darren has *preparation for future research* (*PFR*) as his main learning goal.
From how he talked about the choice of textbooks we can see that PFR is not some unrealistic goal for Darren he happened to talk about. He even shaped his learning around the idea of PFR. When he talked about one of the reference books he used while taking the quantum course, he said,

The nice thing about Landau and Lifshitz is, the way that Landau wanted to teach the class was in a way that people actually do research. Because he figured, people from graduate school are really going to have to do research. Part of the purpose of the class is to prepare them for that research and I’m going to structure my book in a similar manner. And also, some of the things that we are learning in Quantum Mechanics now didn’t even exist at the time that that book came out. They’d just started. And he’d present them in the book because he thought, well, it is important for graduate students to see ideas that aren’t well developed in order to understand how to deal with them.

Here he specifically pointed out that the reason he preferred this book was because the book was written at the time the theory was not completely developed. He thought the author tried to structure the book to prepare graduate students to do research. Instead of learning the theory directly, he was learning the process of how the theory was developed.

When Darren talked about the role of homework in the courses and what he learned from homework, he applied the same PFR idea.

Homework is the most like actually doing research that you get in a core class. You don’t actually go out and do research. They don’t force you to go into a room and say, “okay, you have one hour to figure out this new result, and if you don’t, you’re going to get paid less next year.” You have time to go home and read through different books. You don’t have a closed book research, it wouldn’t make sense. It’s open book research and it’s open book homework.

For him doing homework is similar to doing research in the way that you can use the resources around you and do not have a time limit. This is similar to how
Bransford and Schwartz suggested that researchers could measure transfer in terms of PFL. Namely, researchers should examine how individuals can learn in a resource-full rather than a resource-poor environment [13]. For Darren, doing homework is one of best ways to learn because students get to use all the resources around them to learn about the subject. They get to work with the other students. If they were really lost, the instructor would be there to help them. This is also similar to a researcher’s use the resources around them while they are doing research.

**Passing the Course as an Additional Learning Goal**

Because the OSU qualifier has been eliminated in favor of the grades in core courses, students had to get a certain grade average on all the core courses in order to continue on in the physics graduate program. The new policy reduces the stress of failing one single exam. At the same time, students are forced to put in more effort into getting good grades on the core courses. Other than his preparation for future research goal, another goal Darren had for taking courses is to get good grades to pass the qualifier.

I definitely want to gain knowledge for future research. And that’s my main goal actually with taking these classes and going through these classes, despite what other things there may be. I would say another major goal would be to get a good grade because if I don’t get the good grade I don’t get to go on.

Darren was learning in preparation for future research, but because the core courses grades were used as the pass/fail criterion for the qualifier exam, getting good grades was definitely one of his learning goals for the core courses. Later we will see how this external motivator influenced his learning approaches.
Another graduate student, Henry, mentioned his concern about grade issues as well.

For us here at OSU, your GPA actually matters. So you do have to make sure that you’re not only studying the material to understand it, but also studying to do well on the exams. But hopefully you have a professor who is enabling you to do that. — Henry.

In common with Darren, Henry had understanding the material as his learning goal, but he pointed out that the grade average requirement made him “study for the test.” He suggested that sometimes studying for good grades doesn’t mean the same thing as studying for understanding. He hoped that the professor would give him the chance to understand the material and still get good grades.

Elby raised this same issue in the context of introductory physics. He showed that students believed that a learning approach that led to deep understanding often conflicted with a learning approach that led to getting good grades [61]. Here, two graduate students independently raised their concerns that obtaining good grades might be getting in the way of learning for understanding.

Later, I will show how Darren had to abandon learning for understanding in order to get better grades in one of the core courses. This case will show that Elby’s finding of students driven by the assessment to learn by rote can also happen in graduate level physics courses.

**Perceived Course Goals: Statistical Mechanics**

When I asked Darren which course he liked the most, he replied that he liked statistical mechanics. One of the reasons he liked it was because the course goals of the instructor matched his personal learning goals.

He gave the following example to describe how the lecture went.
He would talk always first about ‘these are the experiments that have been done; these are the things that we know about the physical world, at least as far as thermodynamics is concerned.’ And that whenever we got into the math, he would always warn us. He said, you know we’re going into kind of this, you know, these ‘thistle bushes of math’ and he says ‘we always need to make sure we don’t get lost in the forest, that we always know where we are going’. . . here he said ‘okay, we’ve gotten here, what’s our goal? What are we trying to do with this?’ And having a good goal oriented mindset was definitely very helpful. The way that he structured his tests and such were in a very similar manner.

From Darren’s perception: First, the professor tried to make connections between the knowledge in the textbook and the real experimental results. This would help students understand how what they are learning can be used in a real physics situation. Second, the professor didn’t teach the mathematical techniques as pure math. The course did not focus on how to get the correct answers, but instead, focused on how to figure out which way to go. Being able to figure out the direction is much more important than simply getting the right answer to an unfamiliar problem. I suggest that these are the kind of abilities that Schwartz et al. called adaptive expertise [97].

Darren thought what Prof. S tried prepare them for is,

Ultimately I think that it was, uh, for us to become proficient enough in Statistical Mechanics so that we could ideally go into the library, find a journal article about statistical mechanics, open it up and say, ‘oh, I know this, these symbols.’ We may not be able to understand everything about the article, but we could at least start to understand, well, this is the main idea of what the article was about, and this is how people in statistical mechanics and condensed matter would express certain things.

This is very similar to Bransford and Schwartz’s idea of preparation for future learning [13]. The goal of course was not to make sure students could understand all the physics out there, but prepare them to be able to read any paper and start to learn from it.
Well, my personal goal when I’m taking the course is a little bit different. It’s more to, um, to try to understand the techniques. And I’ll be honest, that was one of, um, that was definitely one of [Prof. S’s] goals as well. His goal was to help us master techniques which are important for a future in theoretical physics. He said, you know, he’s a theoretical physicist, so he’s gonna assume all of us are going to become theoretical physicists. He knows this isn’t true but that’s the thing that he knows. So he’s gonna try and teach us important techniques for, uh, for theoretical physics. And that’s definitely what I try to master the most.

Since he would like to work on theoretical physics in the future, he focused his learning on learning the techniques that would be useful for the future research. His learning focus is on the techniques that would be useful for the research instead of the content of the course.

The other thing that Darren liked about this course was how the homework was structured. The homework problems didn’t come from the end of the chapter. All the problems were designed by the professor and followed a similar pattern.

Because there’d always be this question of, ‘okay now we’ve got this wonderful result: graph it.’ You almost always had to graph your result. ‘What does that mean in the real world?’ — was always the last question. And those were the questions on which we would have the most debates about, just talking with other students. And it encouraged us talking with other students.

Other than getting the answers, students were required to graph their result and interpret their answer in the real world context. Like regular physics questions, each homework problem from this course had one unique answer, which most students would agree on. But the interpretation could have all kinds of possibilities. That disagreement on the homework solution actually encouraged discussion between students. The grading of homework and exam of this course also reinforced the same idea: that getting the numerical answer is not enough for the full credit. Although the
homework and exam problems of this course were still regular problem solving, there was that extra part of “what does that mean in the real world?” Students were encouraged to switch their learning focus from simple problem solving to understanding the deeper physical meaning of each problem.

He graded homework pretty much like he graded the tests, and that was towards the concept. Did you understand what was really physically going on? Would you be able to use this in order to give new results? If you were, and that was what the last question was always about, was about, you know, how would you apply this to these new situations, or what does this look like physically? If you were able to answer those well, and you were able to lead up to it, even if you were missing mathematical factors you would get very good grades. If he didn’t have that, I mean, you could miss a third of the homework, even if you knew mathematically how to do everything, because you wouldn’t be able to answer the last question at all. You’d have all these wonderful graphs and you have no idea what they mean.”

The way the professor graded the tests also encouraged students to switch their learning focus from getting the correct numerical answer to understand the physical meaning. From Darren’s perception of the course, Prof. S consistently applied the course goals — preparing students for their future research/job — into lecture, homework, exam, and grading. Darren perceived that pursuing his personal learning goals was aligned with getting a good grade in this course. He was intrinsically motivated toward learning, so he put in extra effort and time on studying for stat. mech.

Learning Approaches

With preparation for the future research in mind, Darren articulated his learning approach in the core courses.

I show up to the lectures and I take good notes. And I like books that are resources more for graduate classes because after all, we’re in class. We can look through the book and we can go ‘oh, here are the equations
for different situations...’ A lot of people did not like [the textbook] by the way, but I did because I could look through the book and say, ‘oh, these are the equations for the different situations and, oh look this one is being applied differently, there’s a different form to it,’ and spend some time wrestling with it and trying to figure out where that came from, what techniques I could apply in order to relate things and, if I couldn’t figure it out, there was class and I could ask. And so a lot of the educational aspect was built from the class itself.

First, Darren used textbooks and instructors as the learning resources. Instead of treating them as authority and learning from the books or instructors directly, Darren focused his learning on trying to figure things out by himself with available resources. He tried to compare different or similar situations, tried to find out the relationship. He had no fear of failure. He knew that if he couldn’t figure it out, he could always get help from the instructors.

Since the course goals of statistical mechanics matched his personal learning goals, he found himself learning a great deal from attending the lecture.

Because when you read papers about new work, people don’t really know where it’s going or what’s going to happen with it. I mean, it’s important to have a feel of that. So the way he’d move from equation to next was this nebulous but kind of artistic way and it used actual mathematical techniques that would actually be important in research, and the way to think about the problem would be important in research. Instead of ‘yes, I can do this trick where I move this over to this side and make a transformation.’ Its like, ‘well yeah, but why did you do that?’ Instead he leads through, well, why did people want to change this into this eventually, and what does that mean physically? And what kind of results are we looking for? And in that way I would actually work through the problems by basically looking at one equation and seeing if I could figure out what the next equation was without even looking at it. And in some ways I was successful and in some ways I wasn’t, but it was a wonderful way to actually learn the material of the course.

From this quotation we can see what Darren was trying to learn from problem solving. He didn’t care about knowing which trick to use for what kind of problem.
He didn’t care about whether he could get the final answer. He asked lots of “why” questions. He tried to figure out why the researcher took a certain approach and what was the physical meaning behind it. He was not learning the linear problem solving procedure any more. He focused more on how the problem solving approach was developed and tried to understand the reason behind it. When he was solving the problems, he would pretend that the solution were not there and try to figure out the next step. Even when he sometimes failed, he was not discouraged. He thought that was a wonderful way to learn the material by following similar steps the researchers went through including practicing failing.

Over all, because he enjoyed the stat. mech. course, he put in much more effort on studying. He constantly looked for extra materials like journal articles or books to read. (He mentioned that he read three different textbooks at the same time.) He spent more time on this course compared to the other courses he was taking at the same time. He ended up learning much more from statistical mechanics as well.

**Perceived Course Goals: Quantum Mechanics**

The other course Darren took in his first year was quantum mechanics. Darren disliked the quantum course even though quantum used to be one of his favorite subjects. He disliked the course because how the course was structured.

The course goal Darren inferred for quantum mechanics was a focus on solving solvable problems with known answers.

Because there are only a few problems you can go through in Quantum Mechanics. You know. You can go through a square well and you can go through radial potentials and then, um radial wave functions and then of course you just build on from there into spins and... It’s all basically the same kind of model of problems. They all basically have very similar
mathematical tricks. So what people end up doing is they end up downloading the previous exams and reading through the previous exams and of course getting hold of other people’s exams who have done it in the past, and comparing the answer and going ‘oh, so I see the trick to get from here to here, so I’m just going to memorize this one problem and memorize this other problem and memorize this other problem.’ And, um, they lose out on a lot of the more conceptual beauty of it. A lot of them will come through knowing exactly how to solve this specific problem in [the textbook], or this specific problem that [Prof. Q] had on a quiz before. But if you actually ask them how probabilities develop over time, or what exactly the wave function means in a certain experimental set-up — no idea.

Darren viewed the structure of the course as an artifact of the material itself. Because there are only a limited number of solvable problems in quantum mechanics, the learning was focused on memorizing the tricks for solving the similar questions. Since the instructor was teaching the same course the year before, the solution to the homework and copies of tests were available among students who were taking the course. The learning become learning toward specific solutions rather than the physical insights. Learning for this course became an activity of memorizing tricks for solving those problems.

But you always see exactly where you’re going and there’re no questions really as to what this means physically, you just learned how to do some math, something mathematical. And there’s very little physical insight that I’ve ever gained on any [textbook] problem. I don’t think I’ve ever gained physical insight on any [textbook] problem.

In quantum mechanics, Darren perceived that he was solving problems with known procedures. The focus of learning was on how to do some math. He didn’t think he gained any physical insight from doing the problems, because, unlike statistical mechanics, there was no question about what any answer means physically. Darren also talked about the quantum quizzes.
There were quizzes every week, and the most important thing with those is, you look at the quiz, you did develop a solution. And oftentimes the steps in this would have very good physical insights. I’d say more they had good mathematical insights, and you’d memorize those, and of course you’d write them down word for word on the next day.

Since they studied the exact question for the quiz, some students could memorize instead of understand the solution. With the five minutes time limited and pressured situation, Darren didn’t appreciate the quizzes at all.

The quizzes are entirely a waste of time and don’t establish anything except just how fast you can regurgitate a certain answer in five minutes, which I’m not very good at.

**Adjusting Learning Approaches to Achieve Good Grades**

Darren told me that he got a low grade on quantum mechanics at the first quarter but good grade at the second quarter. I asked him what he did differently.

I think that there was another thing in that I was approaching Quantum and Statistical in the exact same fashion, and that was inappropriate because Statistical was emphasizing something different than Quantum was emphasizing. Most of the points I lost in my first quarter of Quantum were because of mathematical details — important because I want to be a theorist. It’s important that I get those mathematical details correct, but I didn’t really emphasize those as much for the class, because I knew that with the other class they weren’t being emphasized as much. So, I would miss all kinds of points just because I didn’t have those.

At first, he focused his learning on understanding with the same learning approach he used in stat. mech. Unfortunately the course had a very different emphasis. Without paying much attention to the mathematical details, he lost a lot of points. After getting the almost failing grade in the first quarter, he decided to adjust his learning approach in quantum mechanics. Instead of learning toward understanding, he took the approach that would help him get better grades.
The studying is definitely different [laughs] I wouldn’t say that you would necessarily study towards the techniques or the concepts, but rather towards a specific answer. The answer becomes much more important.

What I did more in future quarters, is I practiced. Well I practiced for the exam. I’d look at what the exam wanted, and this is so I could make sure that I would actually pass the class, I’d look at what the final wanted, I would make sure that I could do exactly what that specific final wanted, and I could approach the next final pretty much in the same way. For the most part they’d have pretty close questions.

In order to get a passing grade, he started to ‘study toward the test’. He practiced for the exams by studying the exams from the previous year and studying how to solve similar problems. He switched his focus from learning the concepts to getting the correct answer. He took a very different learning approach on quantum from how he studied for stat. mech. He got good grades with this new approach, with the rote learning approach. When I asked him if he learned anything from this course, he answered,

I can’t really tell you all that much about Quantum Mechanics. I can tell you a lot about how to get certain answers, but I can’t really tell you all that much about Quantum Mechanics... I think that I actually have more trouble understanding where the wavefunction comes from and a lot of those other things because of that.

Darren was aware of his rote learning approach. He had learned how to solve the problems and get certain answers. He was also aware that he didn’t gain much understanding of the material.

Summary

I asked Darren why graduate students are required to take core courses. He answered,
I don’t know exactly what the purpose for that is, and I’m not even sure that if it’s all that useful to have in graduate classes because it resembles nothing in research.

For Darren, taking the core courses was supposed to prepare him for the future research. When the instructor had similar course goals, Darren was motivated toward learning such that he would spend extra time to search and study the extended materials.

On the other hand when the courses did not fulfill his learning needs, he still tried to learn for understanding until the failing grade forced him to abandon a deep learning approach and adopt a rote learning strategy in order to get the good grades.

5.1.4 Discussion
Perception of Assessments for Core Courses

Darren showed his frustration on tests from the physics courses with closed book and time limited format. When he focused his learning on preparing himself to do research, he didn’t see the tests assessing any of the research skills he acquired.

In research you don’t have things like the tests and the quizzes, you have things that are much more like homework or take-home tests, or projects, and if we could incorporate projects and take-home tests and stuff like that, I think that those would be much more useful for establishing can we do research well. If I’m getting part of my answer from somebody else, and we’re all helping each other, and my grade depends on someone else, I think that that’s good because my success in research will depend on someone else, and I think it’s good to get that idea in my head that my research isn’t just me in this little island by myself, but I can actually ask other people for help with different mathematical ideas, with different physical concepts; and that oftentimes, it’s my group that makes my research a success and not just me. Ultimately it’s me that needs to put everything together, that needs to understand things, that needs to defend my ideas... But I do have my colleagues. Without my colleagues and definitely without my advisor, I wouldn’t be successful. And I think that if the course were actually taught that way, it would be much better.
Here he described the importance of cooperation while doing research. He talked about how the courses should be structured in a similar manner to encourage cooperation between students. In the regular course setting, the exams are administered in the way to ensure there is no “cooperation”, or so called “cheating”, between students. This was for the purpose of measuring each individual student’s abilities that the instructor need to make sure the test is fair for every student. On the other hand, the closed-book and time limited individual tests have also limit the kind of abilities a regular exam can assess. Since the exams are time limited, the questions in the exam have to be easy enough for students to finish it in a reasonable amount of time. This means the questions have to be quite similar to what students have done in class or homework. This is one of the reasons why novel questions that test for transfer seldom appear on regular exams. With the closed-book format, the exams are often not assessing how well students can use the available resources to learn about and to structure new ideas. This limits their chance to learn how to learn by themselves outside of classroom setting. Individual exams indirectly encourage competition between students. Not only is the exam not assessing how well students can work with each other, the competitive nature sometimes makes some of the students avoid working with one another on homework assignments when they are not forbidden to co-operate.

The limited focus of assessments also gives students the wrong message of what is actually important for their learning. Students perceived the goals of the courses not only through the syllabus and lecture, but also from the assessment. Since students want to get good grades for whatever reason, they shape their learning around the
assessments in order to get the good grades. The closed-book, time limited, individual tests make them focus their learning on problem solving [61].

*Ultimately it’s me that needs to put everything together, that needs to understand things, that needs to defend my ideas.*

Here Darren gave us an important message. At the graduate level, the most important thing that needs to be assessed in the exams is whether students are able to put everything together and form a coherent understanding of the material. It doesn’t matter how many problems they can solve in a closed-book, time-limited exam. It doesn’t matter if they get the idea from another student or they need to work together to form an answer. Assessments for graduate level courses should focus on more than only the content knowledge or problem solving. Graduate students need to be prepared to do research in the future, that is, they need to be able to learn new ideas and study unknown questions by using the available resource around them. Only when the assessments include some of those elements will the students start to perceive learning to be a researcher as part of the course goals.

**Learning for the Grade**

Extrinsic motivation is always an un-ignorable driving force for school teaching and learning [29]. While some teachers “teach to the test,” we can think of a significant number of students “learning for the grades” as well. There should be no surprise that graduate students might “learn for the grades” too.

I asked both Charlie and Darren the grades they got from quantum and stat. mech. From their grades and discussion we can see how their grades had been the influenced by their approach to learning. Among graduate students, getting a B+ on core course is considered as passing grade. Charlie got A- in both courses at the
first quarter and B+ in both for the second quarter. He also told me that he believed he could get an A until he took the final exams. On the contrary, Darren got an A on stat. mech. but B- for quantum mechanics. He considered himself to be failing the quantum course. Then, after he adjusted his learning approach in quantum, he ended up with A in both courses for the second quarter.

For Charlie, he got the above average grades; A- on both courses in the first quarter. This fostered his belief about learning that knowing is learned. With the belief that he was doing well in the courses, he stayed with his rote learning approach. When he did not do well on the exams on the later quarter, his reason was,

I don’t think that was the lack of preparation. They were just, the final was really hard. — Charlie

For Darren, he knew he did well in stat. mech., not because he got good grades in it, but because he had good understanding of the materials. In other words, he knew he had learned the material well. We can see this understanding by how he described the course. In quantum mechanics, he tried to approach his learning the same way he did with stat. mech. Not only was he frustrated because he did not gain more understanding of the material, he ended up with a failing grade in the first quarter. Since the grades do matter, he had to abandon his successful learning approach. Instead, he focused on how to get good grades, namely, he practiced for the tests. Darren did it so well that he got an A for the second quarter. But he also realized that he didn’t learn for understanding.

It is not easy to have students take a deep learning approach. It requires both instructional techniques that promote deep learning and students who understand how to take a deep learning approach. When a student who doesn’t know how to take
a deep learning approach encounters a course that promotes a deep learning approach, the student might stay with his/her surface learning approach. An example of this would be Charlie in the stat. mech. course. When a student who has perfect idea of what deep learning means, finds him/herself in a class that doesn’t support deep learning he/she may revert back to a surface approach. Darren is a good example of this.

5.2 Case Study 2: Classroom Learning Versus Doing Research

In my interview sample, Brian was an interesting and unusual case. He had four years of research experience in his undergraduate education. Most students who plan to attend physics graduate study try to get some research experience during their undergraduate education, so it is quite common for physics graduate students to have some undergraduate research experience. (This is sometimes called research experience for undergraduates, or REU. See Chapter 2.) On the other hand, most of these research experiences in the undergraduate program last only a short time — from one summer to a year at most. Some students participate in multiple research projects that add up to longer time. Brian was different in the sense that he was working with the same research group on a continuing research project for four years. That was enough time for him to observe how research is done and become a leader of the research project. During his undergraduate study, he grew from a novice to a researcher. At the end, he and his research group were able to produce enough important results to publish a paper on their work.

Brian was a first-year physics graduate student at the time of the interview. He was taking quantum mechanics and E&M at the time. At the same time he was
looking for a research group to work with for his first-year summer research. He did his undergraduate study at a four-year college. The physics department he got his undergraduate degree from was a small department where most professors knew all the students. The program encouraged students to participate in any research, but it was not required. Brian described in the interview that, in his undergraduate physics program, students knew professors in person early on, and that made it much easier for them to find a research group to work with. His research group included one professor and a few undergraduate students from different departments. The group also interacted actively with some faculty from other departments and there was a technician to support their experimental needs.

5.2.1 Learning in the Classroom Setting

Brian’s Learning Goals, Knowledge Model, and Learning Style

When Brian talked about taking physics courses, he described himself as a very unmotivated, passive learner. He treated knowledge learned in the classroom setting as a form of substance, which can be transferred from the instructor to the students directly. When he was asked what he was doing during the lecture, he answered

Really it’s just taking classes. You sit there. You’ve been brain-washed by lecturer.

Well, often times, you sit there in the morning. Okay. He is probably talking something important now, I will copy down notes from the board and learn it later. Or you could be engaged. But it doesn’t, it’s not the same, it’s just classes. It’s just professor presents materials. Student remembers, copies material into brain. There’s not whole lot of thinking involved.

He pointed out that in the lecture students have the option of being engaged or not, but he chose to copy the notes down mindlessly for studying later. The kind of
learning he described during the interview is equivalent to memorizing the materials. From the following quotation it is clear that for Brian, “memorized” means “learned.” He described preparing for the tests by reading the notes and books several times to gain familiarity.

Well, the best way of learning is looking at something over and over and over, five times or more.

There is no evidence of active integration of information to construct understanding when Brian talked about learning and studying for the courses. He appears to believe that reading the same material more times is sufficient to prepare for exams. However, as I have mentioned in Chapter 3, research has shown that repeated exposure to the material does not necessarily lead to deeper understanding [87].

Because the professor is always correct. Well, for the core classes I am in now, the textbooks are pretty much, have been around forever. It’s the field I’m sure if there is some glaring error it would have caught way before me. And being a student doing, going through the problems, I mean, you’ll catch any glaring errors you find. You just assume that professors are correct. They write the test, they give you the grades.

Brian thought all the knowledge he received in class or from textbooks is certain, that there is no doubt that the books and professors are always right. With this belief, his learning approach is passive. Learning for him is to remember what was shown in class. His beliefs about knowledge and learning are consistently reflected in his perception of classroom assessment.

[The exam] demonstrates more clearly the knowledge you have. Because if you look at students’ scores, everyone does great on homework. When it comes time, exams are what differentiates those who know it and those who don’t.

Here he defined “those who know it” as,
A student who understands the material enough and who has remembered enough to perform a problem that’s very similar to what they’ve done on homework on the exam.

From this we can see his focus on assessment is on assigning grades rather than giving students feedback. It is clear also that the learning goal Brian perceived was being able to solve similar problems. Although the problems graduate students work on are way more complicated and difficult than introductory college physics problems, the process of learning the exact procedure to solve similar problems differs very little from the introductory level students who memorize equations and then plug-and-chug. This is appears to be a more sophisticated version of rote learning for physics graduate students.

**Locus of Authority**

As mentioned above, one possible reason for Brian to approach classroom learning passively is that he viewed the goals of course work as finding answers to problems with known answers.

You get this rotten E&M problem and you have to solve this... some horrible integral, you can spend hours solving this integral. Whereas that’s hours on something that you fully understand, that should work, you know it works, because generations of students before you have done the same problem, and you’re not really learning anything, except some little, um, small detail of how to solve this particular math problem. Whereas reading a textbook or notes gives you much more information in a shorter period of time.

Since the problems he encountered in class had an existing solution, and the professors are the ones who held the keys to the answer, there was little reason for him to question the correctness of the information he received in the classroom.
He trusted external authorities, the professors and textbooks, completely and never questioned the information he received.

Because the professor is always correct. Well, for the core classes I am in now, the textbooks are pretty much, have been around forever. It’s the field I’m sure if there is some glaring error it would have caught way before me. And being a student doing, going through the problems, I mean, you’ll catch any glaring errors you find. You just assume that professors are correct. They write the test, they give you the grades.

Since the professor held the keys to the answer and the power of giving grades, he didn’t see himself as able to make any judgment either. That made him rely on external evaluation to assess his learning.

**Motivation**

When Brian was asked about what he thought the courses prepared him for, he answered, “I have a suspicion that I’m not going to use much of it.” It is clear that he has little idea of the goals of taking those classes. Since he has little idea why he was required to take them, he relied on the external motivation, homework requirements and exams, to keep up with the work. At the same time, since he was not intrinsically motivated, his approach to learning was in the mode of work avoidance. He described in detail how the instructor should structure the courses around lecturing so he could attend the lecture without being actively engaged in the learning process. At the same time, he thought instructors should assign grades on homework so that students would be motivated to work on them. During the lecture, the instructor should call on individual students with questions to keep students paying attention. He also said that quizzes were a good way to help students keep up with their work, but only pre-announced quizzes are good for him.
When Brian was asked what he got out of the courses, after a long pause, he answered,

I don’t know… Not much. I mean there’s a lot of math for E&M and a lot of frustration for quantum, learning the new notation and whatnot.

This quotation suggests that Brian does not have clear learning goals for the core courses. He appears to view his motivation for taking the course stemming from the fact that he is required to, and his primary goal is to pass the courses.

Brian’s view of learning in the classroom setting is consistent with absolute knowing in Baxter-Magolda’s four ways of knowing. He thought that the instructor is responsible for presenting the materials clearly, and they should “motivate” (force) students to learn by giving tests and grades.

[Dr. E’s] a very good instructor, he’s almost what my ideal instructor would be like. He goes through the material, he does at least thoroughly, he goes through the material well. He… One mark of a very good instructor is that at the beginning of every class, he’ll review the basic ideas that you did in the class before that, kind of put it on the board and say okay this is what we’ve done guys, and now here’s what we’re doing go through it… an announced quiz is good. It keeps you, it forces you to stay up to date along with homeworks every week.

Although Brian’s approach to classroom learning doesn’t sound good, he is not completely unmotivated toward physics. He is still looking for something inspiring in class. When he talked about what he liked about some lecturers,

The part I like about him is he’ll go through the math and as he is going through, he’ll explain it and he’ll explain in different terms than the text, which helps you enhance your understanding. Not only that, he’ll throw in some example,… it’s something new, it’s something interesting, it’s a little extra. [The textbook] doesn’t say anything about that… Oh, so we learned all this, here’s why, it gives you a reason to continue learning it otherwise you’re just oh okay, that’s nice, why am I learning this?
Although he relied on external motivation to keep him working for classes, he still appreciated when the instructor made the effort to make connections between the course material and real physical situations. From the interview, it is clear that he wished the core course instructors had spent more time on why he needed to learn the stuff he was learning.

Summary

In summary, Brian didn’t see the goal of learning in a classroom setting. He studied because he was required to take the courses and pass it. He relied on external motivation to keep up the work and he chose to take the approach that minimized his effort. He perceived knowledge as disconnected facts and he used words like “memorize” and “remember” to describe learning. For him, learning is simply receiving the information from the lecture, and he believed that the professors and books are always right so that the authority for making judgments about knowledge lay with the instructors rather than with himself. Despite his passive approach on learning, clearly he was still looking for more intrinsic motivation that would give him the reason why he was required to take those courses. It would be interesting to see how he would approach learning if the courses were taught differently. Unfortunately none of the courses Brian took were structured so as to encourage active learning. As a result there is no way to tell whether Brian would adopt different approach in a more learner-centered learning environment.
5.2.2 Teaching in the Classroom Setting

Brian’s Perception of the Teaching Environment

Brian was teaching the introductory physics recitation at the time of interview. He described teaching as “it’s frustrating because I’m not really teaching so much as just being a tutor.” From here we can see that since most recitations required TAs to solve problems for students, he didn’t even consider what he did in the recitation as teaching.

He realized that he needed to engage students to make the learning happen. He tried to get student to participate in class, but he found it difficult.

The biggest thing is that my students don’t like to participate, and the more you don’t let them participate, the more they don’t want to and the quieter they get. And finding ways to just get them to answer questions and whatnot is challenging.

One reason he thought it was necessary to engage students in the introductory courses is because they need more structured instruction. At the same time he thought that graduate level courses don’t need student participation, because the graduate students should actively engage themselves in learning.

For the freshmen undergraduates it is necessary to get them to participate because they are not mature enough to teach themselves, but as you progress forward, on in your classes, it should be less and less because presumably, from the point of grad level classes, you should be making yourself participate. You should be engaging in the material as the lecture is going on.

This agrees with his expectation of the graduate level courses that there should be minimum participation in class. He suggests that the graduate students should be given the freedom to choose to participate in class or not. He thinks students at the graduate level should be mature enough to engage in the material during lecture. At
the same time, it does not appear that he was actively participating in the lecture when he was taking core courses.

**Teaching Approach**

What kind of teaching approach would Brian adopt if he were teaching in the future?

Well, it depends on who am I teaching. If it’s 111 students, teaching is presenting the material and finding a way to get the students to understand it and engage it. Which is pretty much the same all the way up, but the definition of teaching changes as you become more of a self-starter, as you become a grad student you’re supposed to learn yourself. It goes to the level of just presenting the material, throwing it out there and let the students do with it what they want to.

From here, it is clear that his definition of teaching/learning is equivalent to presenting/receiving material regardless of the level of the course. There is no suggestion of students constructing meaning when he talked about teaching. This suggests that when he said get students engaged he meant to get students pay attention to the lecture. This is very different from the general understanding of active engagement in physics education research [17].

**Summary**

Brian’s view of teaching and learning are consistent with each other. As a student, he expected the instructor to provide structured knowledge that he can receive without much mental input on his part. As a teacher, he tried to teach students by presenting the material and expecting them to understand it. He argued that graduate level courses don’t need to get students engaged because graduate students should be active learners. At the same time, he wanted to be “brain-washed” and
“fed” information in the lecture, and expected to put in minimum effort for his own learning.

5.2.3 Learning in the Research Setting

Brian’s Perception of Doing Research

From the previous section, Brian seems to be totally unmotivated toward learning and teaching. He was also very driven by external sources of authority: He thought that external authority is the source of knowledge and the instructors hold the key to evaluating the veracity of that knowledge. When he talked about research, he seemed to be a totally different person.

Brian attended a small branch university only offering an undergraduate degree. He majored in physics and worked with a research group on a research project for four years. At the time of interview, he and the research group had just completed a research paper ready for submission.

When he was asked what doing research meant to him, he answered,

Going through a series of experiments to prove that something is doing what you think it’s doing...you have to have the ability to work with others very well and communicate your ideas.

Definition of doing research? From an academic point of view, it helps, it gives students the ability to reason and think on their own, and learn to teach themselves. Learn to, uh, [long pause] it’s not just about getting the end product, the finding, the discovery or whatever, it’s developing yourself personally as a logical thinker.

In this description there is clear evidence of a process orientation towards research. Similar to Brew’s journey-type researchers, Brian talks about the personal transformation of the researcher, not just the end product of the research. Brian’s focus on
developing thinking skills through research is a theme that runs throughout the en-
tire research part of his interview. Other than communication skills, he thought the
most important skill he learned through doing undergraduate research is independent
thinking.

The ability to think independently of your advisor... To be a true
researcher, and to be a good researcher, you have to know what’s going
on and know, as you going through the steps, you do the experiments,
you get the result you should be thinking in your mind, now this is an
explanation, you shouldn’t be, oh, let’s go talk to the advisor see what he
has to say.

**Locus of Authority**

It is clear from his undergraduate research experience, Brian has the expectation
that doing research means he has to make his own judgments. He should not rely on
his advisor to tell him what to do.

My expectations for research include a lot of being in the lab and
figuring stuff out for myself.

When he was asked about his expectation of his future research advisor, he replied,

I would expect guidance, but I don’t expect spoon feeding. I would
expect him to say here is what we’ve been doing, there is some leniency
in what you choose as the project you want to work on, read about it and
tell me what you want to do, we’ll go from there. And then as I got into
it I would expect little nudges this way and that way, constantly pointing
back to the advisor, but I wouldn’t expect the advisor to be completely
in control and say okay, from 9 to 10 today you’re going to wash beakers,
and you’re going to do this experiment this way... Guide, prod you in
the right direction. Not tell you this is the right direction, but just kinda
nudge here, here, here, and make you find out for yourself that it’s the
right direction.

He expected some guidance from his advisor, but he didn’t want the advisor to
show him the clear path. He wants to be able to figure things out by himself. He
wants to be the one who makes the decisions and judgments about what to do next and how to do it. The advisor is there as a resource to provide valuable comments when he needs them. From his research experience he has the confidence that he can do research. And he wants his future advisor to give him the chance to be a real researcher to lead the research project.

The undergraduate research experience also affected Brian’s view of evaluation in the research setting. Earlier, we saw how he was authority oriented in the classroom setting. In the following quotation, he talked about reading research papers.

I mean when you are reading through, you are never totally hundred percent believing it. You’ve always a skeptic. Is this guy doing this right? ...Cause they were claiming that they had, they had transfer when they clearly didn’t. I mean, they actually said in the end, well we’re not a hundred percent sure... You are continually asking yourself, how is this applying to what I am doing? How can I use this? And of course if you run across stuff that you don’t know, you want to make sure you find out what it means if it’s relevant... Well, as an advanced research student, you have a purpose for reading the paper. You know what you are looking for. So you’re constantly asking yourself, how does this fit in, does this make sense? Does this group, this method concur how I’ve done? Did they goof up in some way? Am I goofing up? You’re continually checking back and forth to make sure everything is consistent.

Unlike the way he trusted that textbooks were always correct, he was very skeptical about claims and results in published papers. While he questioned other research group’s data, he also questioned his own experiment results. He didn’t expect his advisor to tell him which one is correct, he tried to examine all the information out there to make his own judgment. Not only was he evaluating other people’s work, he examined his own constantly as well. Brian’s way of knowing for doing research is contextual knowing, namely, the ability to evaluate all the available information and make the best decision according to that information [59].
To be a true researcher, and to be a good researcher, you have to know what’s going on and know, as you going through the steps, you do the experiments, you get the result you should be thinking in your mind, now this is an explanation, you shouldn’t be... oh all-knowing advisor tell me what to do next.

For Brian, knowledge in the research setting should not simply be accepted as it is. Everything has to be carefully questioned, examined, checked, and compared. Through learning how to self-assess in conducting research, he was able to tell whether he was on the right track. This would be the first step for the self-directed learning and/or research. In summary, Brian appears to view authority in the research setting as located within himself and he appears to have developed many of the features of self-authorship.

**Learning to Become a Researcher: The Importance of the Environment**

Brian’s description of how he learned to become a researcher and how he progressed towards proficiency in his research group show that his success was not an accident. From the descriptions below, he shows us how a research environment structured around the concepts of cognitive apprenticeship and legitimate peripheral participation can successfully work to allow a undergraduate physics student to transition from a novice to an expert researcher.

The research part of interview was focused on Brian’s undergraduate research experience. He described the research environment he first encountered as a freshman physics student as follows:

...at my school, the research was structured so that they expect you to be ignorant when you first came in. They throw all those papers at you. Of course, you read them, it helps. But they realize you’re not going to know it. So a lot of my tasks for that first year were rudimentary. It wasn’t as low as, you, you go wash beakers freshman. But it was just
simple stuff, and I liked my experience in that my advisor gave me a lot of leeway to do what I wanted to do. And as I became more interested, I’d try something out. And I’d be like oh, look what I discovered. He would be, great, now we are ready for the next step and he’d nudge me forward in the right direction.

He described learning how to conduct experiments by observing others in the lab or coming up with ideas on his own:

...if you’re doing the experiment, typically you just, you either come up with it on your own or if it’s something you’re... If you’re coming in as another student is leaving, you watch them to see what they do, then you learn, you take the ball from there.

Brian described how his level of participation and responsibility in the research process changed over time:

Well, it changed over the course of my stay there. As I got more proficient, I was put more on my own.

From these quotations we see during Brian’s undergraduate research experience how he learned to become a researcher. At the beginning he was put to work as soon as he joined the group. The tasks he engaged in were simple at first, but not meaningless labor. Both cognitive theorists [19] and experimental researchers [80] have shown that it is essential for successful learning environments that the novice researchers/apprentices feel that they have legitimacy and real impact on the research/craft process. As time goes on, they move from the periphery of the group (engaging in simple but meaningful tasks) to a more central role as they become more proficient and take on more responsibility for research decisions. Brian described this as he took on more responsibly to figure things out by himself. He also felt that he was given a lot of freedom to make decisions on what to do. Overall, his undergraduate research work started with simple tasks and gradually increased in complexity.
He was put on real research tasks rather than mindless routine work. He was also slowly put to work on his own and allowed to try out his ideas. All of these features agree with the methods suggested for cognitive apprenticeship: increasing complexity, situated learning, and scaffolding the learning process and then gradually removing it [20, 82]. Because of this learning environment, Brian is very motivated toward doing research and has full confidence that he has the ability to do it.

Motivation appears to be a critical element of the research environment. Brian not only learned the skills necessary to conduct a successful experiment, he also developed a sense of determination and a resilience to initial failures.

I got to see the perspective. While I was there I didn’t know anything, uh, I was flustered a lot, and then I realized, uh, if I do the experiment it’s not going to work, I’m going to not get upset about this, and we’re going to repeat as many times as it takes.

From the motivational research literature, one way in which researchers measure whether students are motivated or not is by how easily they quit a challenging task when they are faced with difficulties [28]. Brian suggested that knowing what to expect helped him be more patient with the progress of his work. Some studies show that students quit learning when things get difficult because they expect it to be easy [28].

When students are in the classroom, they often see professors solve problems with ease. The professors always know exactly what they need to do to get the solution. I suggest that they are constructing an image of an expert who doesn’t need to go through the process of making mistakes. Students try to avoid making mistakes, which in the research setting, may translate into students who are unwilling to try out their own ideas. What Brian said here is that research is not an easy process. He
saw his advisor as a researcher struggle with the experiments. The experiments don’t always turn out as what they had expected. In his research experience, he learned to be patient in the face of difficulties. He also became more patient with his learning process in the research setting.

Persistence in the face of adversity is one of the important qualities of a task-involved learner. I suggest that we should design educational settings where students can see that learning is not an easy process so that they can have a better perspective on their own learning and what is necessary for them to succeed.

5.2.4 Teaching in the Research Setting

Since Brian was in the same research group for four years, he had a chance to grow from a novice researcher become an expert on that research topic. When new students joined the group, he was able to help them out and teach them something. Thus Brian was involved in “informal” education within his research environment.

What is remarkable is how different his conception of learning and teaching in the research environment is from his conception of learning and teaching in the classroom setting:

I saw students come, and it was like looking at myself all over again and watching this learning process going on, and by the end I had the unique ability of actually tutoring students, uh, to essentially be a pseudo-advisor. Like oh you shouldn’t do it this way, you should do it this way and trying to get them to learn themselves.

From this quotation we can see that Brian’s approach towards teaching and learning in the research setting is process oriented and learner-centered. He wants to help students engage in the learning process, rather than giving them the right answer. To teach or tutor in a research setting, he referred back to his own experience of learning
to do research. He chose to give the new students a similar learning experience by getting them to figure things out themselves. When he was asked to compare teaching in a research lab to teaching in the classroom, he replied,

Uh, that’s a different form of teaching. It’s not the same as classroom, students doing research are there because they want to do it, so they’re motivated. And they’re often teaching themselves, and they only come to you when they get stuck or they have questions. So you’re like, you could give them the answer and send them on their way or you could go about it in a more roundabout fashion so that they come up with it themselves, but it’s different, it’s more fun.

It seems that he had chosen an approach towards teaching based on the goal of teaching and the students’ motivation toward it. Students in the research lab were there because they were interested in doing research. They are motivated to work. For Brian, it is possible to teach/help those students by letting them come up with their own way. On the other hand, classroom learning is boring and he was not motivated toward teaching either.

That was different, that was research, that was fun! As opposed to, okay 111 student, I know you don’t wanna be here and don’t wanna learn this, but I’m paid to teach you, so here it is.

In the classroom setting, he chose to teach in the way that matched how he perceived classroom teaching. Namely, focusing on getting students to remember facts. From how he talked about it, it is clear this is not just the matter of how motivated the students are, his choice of approach also lies in how he is motivated toward research versus classroom learning.

On the other hand for doing research, whether it is learning from his advisor, or teaching his fellow students how to do research, he understands that doing research is about sense-making, making judgments, and comparing experiments — it’s all about
acquiring the necessary skills to be able to conduct the research. He thinks that the advisor is there to provide guidance, not there to give step-by-step instructions. He takes a learner-centered approach: learners should figure things out by themselves. External authority is not important any more: he expects that the learner has to make the judgment about whether the information is valid or not.

5.2.5 Discussion

It is surprising to compare how Brian worked on his graduate core courses to how he approached doing research. For someone who is pretty much a self-learner, who knows how to be an active learner, and how to engage in discovery in an unknown field while doing research, it is surprising that he approached learning in classroom setting in such a passive manner. Or maybe it is not that surprising at all. It is clear that his meta-cognitive knowledge about how to learn in the research setting didn’t transfer from the laboratory to the classroom-learning situation. However he was able to transfer his ideas of knowing between learning and teaching in the same setting.

There is no reason for him to transfer the active learning approach to the classroom setting since that is not the expectation that he perceived from the courses. In the laboratory, the goal of learning is about acquiring the thinking skills to conduct research, but in the classroom, it is about acquiring disconnected facts. While doing research, he was intrinsically motivated to gain true understanding. On the contrary, taking courses is all about getting a passing grade. Brian relied on external motivation to help him meet the minimum requirement. There is no contradiction for Brian since the different goals motivate him to choose the appropriate approach for each situation.
The following quotation shows how his expectations made him choose his approach for learning in the classroom setting. When he was asked what he would expect of advanced graduate courses, he replied,

Well, I would like [the advanced courses] if it was like the core courses, I can mindlessly attend lecture. But I somehow suspect that the more advanced means more specific, means less students, means, uh, weekly meetings with professor, okay did you guys read this chapter? What didn’t you understand? More of I teach myself sort of thing, which I can understand is the ultimate goal. I mean, I’m fairly good at [that] from doing the research.

With the full understanding of what true learning is from doing research, why would he think learning in a classroom setting would be so different? From the following quotations, it becomes clear.

Yeah, [doing research] helps you be a self-learner to some degree. . . The ability to pick up the textbook and learn it without the aid of a lecture [long pause] I don’t know, I still just see the coursework as typical coursework I’ve done before. I mean, there’s a lecturer there so I’ve got the expectation of being fed the information in lecture.

From doing research, Brian has learned how to think independently and self-direct the research process. He recognized that he knows how to be a self-learner to direct his own learning. With the learning environment in the classroom being so passive, and there is a lecturer there to present the material, even he was able to be a active learner from doing research, he chose the approach of least effort. Previous studies [43] have shown that students who have been through learning environments that require a deep approach to learning revert back to taking a surface approach when the environment doesn’t support deep learning approach any more. In Brian’s case, his belief about learning in doing research didn’t transfer to classroom learning because 1) the classroom learning environment doesn’t promote learning for understanding,
and 2) he sees that he can afford to take a surface approach to classroom learning and still get a passing grade.

5.2.6 Summary

From Brian’s interview we can see that with the ability to learn on one’s own while doing research, he still viewed course work as being fed information passively. He is a successful active learner while doing research. Due to the way he perceives courses, his active role doesn’t transfer into classroom learning. The same applies to his teaching approaches. While teaching in the classroom, he perceives himself as a source of information for the students. Even though he realizes the need to engage students during the lecture, he still views students as passive receivers of knowledge. There is no need for the students to be actively constructing meaning in class. The active engagement serves only to keep students focused on the lecture, not for them to engage in the construction of understanding.

Brian didn’t see that the training he got from doing research has any help in his course work, since what it takes to be successful in class are rote learning approaches like memorization, and reproduction of mathematical derivations, which are both very different from doing research.

In doing research, Brian was comfortable using his own judgment to decide what the research result meant. For doing research as an undergrad, he had already developed enough skill to think independently from his advisor, the authority figure. In his view, the advisor was only there to provide some minimum guidance. He was the one who needed to carry the research project.
On the other hand, for the course work, because the material is well developed, the books and professors are the absolute authority. There is no room for doubt. His approach towards learning those materials became focused on receiving knowledge. There is no motivation for questions and debate. Even the homework is just for reproducing known results. Brian’s different behaviors in the classroom and research settings are summarized in Table 5.1.

<table>
<thead>
<tr>
<th>Environment</th>
<th>Classroom setting</th>
<th>Research setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Learning</td>
<td>External locus of authority: professor and textbook are always right</td>
<td>Internal locus of authority: making self judgments</td>
</tr>
<tr>
<td></td>
<td>Externally motivated</td>
<td>Intrinsically motivated</td>
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<tr>
<td></td>
<td>Passively driven</td>
<td>Actively involved</td>
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<tr>
<td></td>
<td>Learning as remembering</td>
<td>Participate in real research</td>
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<tr>
<td>Teaching</td>
<td>Teacher-centered approach</td>
<td>Learner-centered approach</td>
</tr>
<tr>
<td></td>
<td>Focus on content</td>
<td>Focus on process</td>
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</tbody>
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Table 5.1: Comparison of Brian’s learning and teaching approach in classroom and research settings

5.3 Case Study 3: Irvin — Problem-solving as the Overall Goal

At the time of his interview, Irvin was close to finishing his degree. Irvin had been in the physics graduate program for five and half years. He had been working on research for a while and planned to finish his degree within a year. He had completed all the course requirements and exams (qualifier and general). At this point, he was working on research only.
Unlike Brian, Irvin didn’t have any undergraduate research experience. During the interview, I discovered that he had switched research groups twice during his graduate career.

Throughout the interview, Irvin showed a special focus on problem solving. When he talked about learning and teaching, his main focus was on problem solving. When he talked about research, not only did he use problem solving as an analogy to talk about doing research, but he treated doing research as solving problems as well.

5.3.1 Learning in the Classroom Setting

Since Irvin had been working on the research for a while, I wondered if doing research helped him see the reason why he was required to take all the physics core courses. Irvin responded as follows:

I think it’s primarily tradition. Everybody learned E&M, so everybody else has to learn E&M. Then again, you know, there is some merit to it that, well, you see certain problem-solving techniques crop up time and time again, and you see the harmonic oscillator shows up everywhere, so it pays to learn the harmonic oscillator. I think primarily it’s tradition, but maybe secondarily there is some sort of effort there to teach these basic problem-solving skills you need later on in life.

He thought that the reason to require every physics graduate student to take core courses was mainly tradition. At the same time he tried to justify taking the core courses by suggesting that a lot of problems that physicists solve are similar to each other. For Irvin, the learning goals for the courses are to learn the problem-solving skills. At the same time, he didn’t think the courses prepared him for doing research.

They sort of teach you a frame of mind. They don’t [prepare you for doing research], I mean, they don’t train you so much. You know, I’m not using E&M on a day-to-day basis, but they do teach you a way of thinking about things. Thinking about things in sort of a linear fashion.
Like many of the other graduate students I interviewed, Irvin thought that the core courses taught him a frame of mind, or a way of thinking. It is important to qualify what frame of mind Irvin is talking about here. He describes it as ‘thinking in sort of a linear fashion,’ which refers to a conception of problem solving as a straightforward linear process. When I probed him further about his conceptions of problem solving, he described solving the problem as ‘having a clear idea how to solve it, just following the set procedures then you can get the answer.’

For the class he liked the most, the reason he liked it was,

Well the professor was very organized and he set things up in such a way that, you know, each next... the next section obviously connected to the last one and there was an obvious progression from point A to point B. And I liked it because he would make an attempt to connect it to the real world, you know, show us videos of phase transitions and things like that. Ya, I liked that class a lot.

From here, it is clear that he liked the material be presented in a linear fashion. The clarity of the professor is important to him and he also likes the professor to make connections to the real world.

When he was asked what did he learn from the courses, if any of them were useful for his research, he answered

Maybe at the time. I think I probably remember absolutely none of it at this point, but yeah, I, hmm... If we’re asking which one I learned the most from, that was...I mean I took a class from my advisor that was just [subfield x] physics and I got the most useful information out of that.

Summary

Although Irvin was not as articulate as Brian about his learning process in the classroom setting, there are a number of things that Irvin says that suggest a) he has
a model of knowledge as an object that is passed from teacher to student, and b) he has an external locus of authority for learning in the classroom setting.

1. Irvin appears to make a judgment about whether he learned the material at the time when he was taking the courses in terms of how much he remembered at this point. He treats “remembering” as “learning.”

2. When Irvin answered what was useful for his research, he focused on the content knowledge he gained (or didn’t gain) from the lecture. Since the materials from the core courses were not directly related to his research, he tended to judge that they were not useful for him.

3. Irvin judged the lecture in terms of the clarity of the lecturer which is one of the characteristics of absolute knowers in Baxter-Magolda’s epistemological reflection [59]. This, again, suggests a model of learning as transmission of knowledge from teacher to student.

5.3.2 Doing Research

Irvin was close to finishing his degree, so the interview focused more on his research. Since he was working at the research at the time of interview, he was able to articulate what he did on doing research in detail.

Perception of Doing Research

When Irvin was asked about what he liked about doing research, he answered,

I like the problem-solving. If the problem is well defined and I can see, you know, see where I am and see where I need to be, and sort of building that path from A to B, I enjoy that, but if I don’t know where the end point is, and when I’m just roaming around in the dark, that gets a little

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aggravating. I guess that’s the thing I don’t like is just being aimless and not knowing what to do next.

For him, doing research is similar to solving problems by a linear process. He enjoyed doing research when the path to a solution was clear, he didn’t enjoy it when he felt lost. So I asked him what he would do if he didn’t know what to do next, he answered,

I usually go and bug my advisor until he tells me ‘do this’, you know, just to give me something to do, do this and we’ll see what comes out of it. It’s really been my only option to this point — go and bug him.

From this it is clear that he expected that his advisor always had the answer for him. When he didn’t know what to do next, his advisor should be able to give him a clear direction.

**Locus of Authority**

When Irvin talked about his expectations of his research advisor, it is clear that he had a view that the authority to make vital decisions in his research was located with his advisor rather than with himself.

If I was him, I would take a more hands on approach than he does. He will sort of give me a direction. He’ll say, well I think you need to go and investigate this wave function in the case of the [X]. Okay, so I’ll go and do that and sort of fumble around with that for a while and maybe sort of branch out and do some other things and then come back to him and show it to him and he’s like, oh well that’s good, well it’s really your research project so figure out what to do next.

Clearly his advisor was trying to get Irvin to take the lead on the research project. That doesn’t mean Irvin didn’t get support from his advisor. His advisor treated him more like a research partner, and provided him with discussion and suggestions. On
the question of what to do next, his advisor made it clear to him that this is your project, go figure it out. Clearly this is not what Irvin wants.

So occasionally he’ll sort of point me in a direction and other times I’ll go in there and he’ll be too busy to deal with me... So what I mean by a more hands on approach is that, you know, he would come down to my office once in a while and see what’s going on and that sort of thing. As it is now, he waits for me to come and find him, and maybe that’s good for teaching me personal responsibility, but, um, while he’s not there I sort of meander off in unproductive directions.

When I asked what he thought the research advisor’s role is, he answered

Sort of a traffic cop. To sort of point the way, sort of... [long pause]. To sort of say, okay well here is the overarching goal. You know, here is the big question, you know, maybe we can make contributions to x, y, and z on that problem, then sort of, okay well turn it over to the student and let them sorta pick out, oh well, this is where I feel comfortable, this is what I’m interested in, and then sorta keep them on track and not let things sort of get out of hand and... just sort of focus things down and say well maybe the goal you have is a little bit unrealistic, but we could maybe do half of what you are thinking or something like that.

It is important to note that Irvin used a “traffic cop” as an analogy for his ideal research advisor. This analogy suggests that he viewed his research advisor as the absolute authority, who is always correct and the authority should never be challenged. For Irvin, a research advisor should always know which direction to go next, and he expected his advisor should always have the answer when he needed it.

Compared to Brian, Irvin had more physics background training since he had finished all the course requirements for the Ph.D. On the other hand, the training from the courses didn’t give him more confidence to do research. The biggest difference between Brian and Irvin is that Brian realized that doing research means working in an unknown area and he feels comfortable to take the lead and figuring things out.
Irvin expected his advisor to point him the right direction and only give him linear problems with known answers.

**Learning to Become a Researcher: The Importance of the Environment**

During the interview, Irvin mentioned that he had to switch research group twice. I asked him why.

I just got bored. I started out trying to do [research field A]. I'd worked like the first few quarters, I was with [Dr. N] and [Dr. G], and there it was just all well, you can't really do anything with us until you understand [subject X], um, you know, read this book, read this book, read this book, um, there was no actual... I mean, to me it didn’t feel like I was doing anything. I was just sitting there reading books, and I got tired of that, and I worked with, uh, [Dr. E] for a couple of quarters, I think. There it was sort of the same thing I'm doing now, you know, it was more of a programming gig than anything.

Unlike the research group Brian worked with, in this research field, Irvin felt that he couldn’t be part of the research until he have sufficient knowledge of the field. And the way for him to learn the field was through reading and studying by himself.

In Brian’s case, he started working on a research project before he fully understood the theory behind the research. Being part of the research gave him the motivation to learn those materials by himself. Here for Irvin, studying the theory was a prerequisite qualification for him to legitimately participate in research. However, without direct connection to the research project, learning the theory appears to be little different from learning in the classroom setting. He got bored and lost interest in that field and ended up switched to another research group.

Comparing Irvin with Brian, we see two very different models for students to get into research. In Brian’s research group, all the students were undergraduates and thus it was tacitly acknowledged that they would not have enough background
knowledge when they joined the group. All the students were put into simple but meaningful work and they were expected to learn while they were working on the research. On the other hand, for Irvin’s research group, he was not considered qualified to work as a researcher even though he had finished all the graduate level courses. Delaying his participation in doing real research not only slowed down his progress on learning to do research, he also completely lost his interest. Not being a legitimate participant of the research group made Irvin give up the research field before he even has a chance to figure out what doing research in that field was like.

Switching research field is a painful process for both the switching student and the research group. Not only do the students take more time to finish their degree, the research group is also wasting their time and resources training the departing student. It is not always possible to prevent students from switching between research groups because sometimes they don’t know if the field would work for them until they start working on the research. If the students need to go through the process of switching, at least they should get the chance to see what working in that research field is like, rather than spending all their time on reading. Applying the concept of legitimate peripheral participation [19] to graduate research in physics, the evidence I have gathered suggests that research groups should make the effort to have graduate students become legitimate participants as soon as they join the group. This is necessary for undergraduate students to learn to do research [80], and therefore it is probably necessary for graduate students as well.
5.3.3 Future Teaching

Although Irvin didn’t seem to have developed an internal locus of authority or self-authorship as a researcher, he did have some good ideas about teaching. I asked him how he would teach if he were teaching the graduate core courses.

It’s all well and good to sit there and solve vector equations, but what does it all mean? If there was some way, you know, of actually demonstrating some of these oddball concepts that I can’t even pull out of my memory right now. I think that would be more effective than having [professor] standing up there and tell me stories about Gauss. That’s sort of my broad brush-stroke of what I would do.

Since he liked the professor who tried to make connections to the real world, he suggested that a graduate level course lecturer should use more demonstrations to show the physics concepts instead of straight lecture.

Well, I mean more like a 131 type course where you have a lab component. You go in there and you actually see $F = ma$, and you actually see circular motion, stuff like that. I would be... without actually having an E&M textbook in front of me, I would be at a loss to tell you what sort of experiments I could devise to demonstrate E&M to grad. students. I mean, I guess the first thing I would do is grab Jackson off the shelf and see what could I do to make this more hands on rather than me just standing up there talking about As going this way and Bs going that way.

He also tried to make an analogy to the introductory physics courses and suggested having a lab component for the graduate courses. Although he had no idea what experiments can be used for those courses, he was willing to make an effort to give it a try.

My goal would be to teach the thought process of problem-solving. Not so much, you know, I don’t care whether they learn about dielectric constants, or permittivity of free space or whatever. It’s more of how do you solve a problem. Again, you know, sometimes you have to just put your head down and try something.
At the end, he didn’t forget the learning goals he had in mind for the core courses. If he were teaching the courses, his focus would still be for graduate students to learn the thought process of problem solving. From this quotation only, it sounds like he would like to focus on the process goal more than the content goal. But from the interview of the research part we know what he meant by ‘problem solving,’ namely applying set procedures to solving known problems. That means his teaching approach is still teacher centered.

5.3.4 Summary

Overall, what we can conclude from Irvin’s interview is,

1. **Irvin was unmotivated toward doing research.**
   
   He switched research group twice during his graduate career. While he was working with the previous research groups, he was not allowed to participate because he didn’t have sufficient background knowledge of the field. He said that he got bored while he was put on reading on his own. He might have lost the motivation toward research when he switched between groups.

2. **Irvin’s locus of authority was centered on external authorities**
   
   As both learner and researcher, Irvin’s locus of authority was on the external authorities like the professors or his advisor. He wanted professors to present clear lectures for him to learn. And he expected his advisor like a traffic cop to tell him what he should or shouldn’t do next.

3. **Irvin transferred his beliefs about learning and teaching to doing research**
   
   His model of teaching and learning is of the form: teacher presents materials and
students receive them. Knowledge for him means content knowledge rather than the abilities gained in the learning process. For doing research, his expectation of the advisor/advisee relationship is the same as his belief about teacher/student relationship. Since he was a graduate student, he expected his advisor to show him exactly what to do just like students expect teacher to present material clearly.

Irvin’s choice of approach toward doing research is possibly a combination of his belief about learning (being a graduate student) and a lack of a good research learning environment earlier in his research carrier. However there is no way to know whether Irvin would have adopted a different approach if he had a research experience similar to Brian early on.

With his passive approach, Irvin was able to complete the course requirements and was about to finish his graduate study. I asked him if he felt comfortable doing research by himself, because that’s what he needs to do when he starts working on the real job. He replied:

Well, it’s just one of those things. You just do it. You put a smile on your face and act like you know what you’re doing just like you would anywhere else, I mean, I wouldn’t feel comfortable. . . I think comfortable is overrated. You only, you’re only comfortable where there’s really nothing left to learn. So, um, I mean there’s always. . .I mean if I went over to [X] and wanted to do [subfield Y] with them, I would be a lost ball in high weeds, but you’ve got to. . .I mean I realize that I have this sort of skill set that I can go and I can pick up what I need to know and go on from there.

Irvin didn’t have the confidence to conduct research on his own, because he didn’t think he knew enough to perform research in a context where the result was not yet known. At the end, he argued that he has the skill set that he would be able to learn
what he needed to know. This shows that he did have the idea of *preparation for future learning* [13]. He realized that he wouldn’t be doing the same research after he finishes graduate school. He would need to learn new things on his own when he is conducting research in the future.

### 5.4 Summary

A number of important themes have been explored in this chapter. Charlie and Darren have shown us how students’ learning goals and expectations of their physics courses interact with the course goals of the professor teaching the course. Darren in particular showed how he consciously and successfully altered his approach to a course to get a better grade, while sacrificing deeper understanding of the subject at the same time. Brian has provided us with a model example of how a student can successfully transition to becoming an expert researcher while simultaneously compartmentalizing his beliefs about knowing in the research context separately and differently from his beliefs about knowing and learning in the classroom context. Irvin provided us with a contrasting case of a graduate student who appears to have failed to find self-authorship as a researcher and remained reliant on his advisor for most direction and guidance. Irvin also provides us with some clues as to why some students may fail to make the transition from student to researcher and fail to develop self-authorship.

Although these case studies highlight very different aspects of the graduate physics program and how students learn from it, there are a number of common theoretical ideas that these case studies share in common. I will discuss these ideas in Chapter 6 and provide some suggestions for future research.
CHAPTER 6

DISCUSSION, INSTRUCTIONAL IMPLICATIONS, AND FUTURE DIRECTIONS

For most physics graduate students, one of the goals of their graduate study is to learn to become researchers. The physics graduate program is structured in a way to fulfill that outcome as well. As several students mentioned in their interviews, no one gets the Ph.D. by passing all the courses. In addition, for those graduate students who want to stay in academia, they also need to be able to teach. They need to be able to teach in the classroom setting and advising students in a less formal research setting.

In order for graduate students to do well at both teaching and research, they also need to have sufficient physics knowledge, the materials for them to teach or the materials for them to do research. Physics graduate students are learning how to do research and how to teach as well as learning the physics knowledge.

In the previous two chapters, we have looked at what graduate students think about classroom learning as well as their teaching and research experiences. In this chapter, I will discuss ways in which the physics graduate program could be structured to better prepare graduate students for their future roles as researchers and teachers.
I will also suggest possible future research directions on the topic of physics graduate student education.

6.1 The Transition from Student to Researcher

As Darren said in his interview, ultimately, physics graduate students need to be able to do research. That is, they need to transition from students to researchers. There are two very important elements of becoming a researcher.

1. A researcher needs to be able to learn in an unknown area.

2. A researcher needs to be able to think independently.

These two goals are still applicable even if the graduate students decide not to work in the academic setting.

Being able to learn in an unknown area means graduate students need to learn for PFL transfer [13]. Being able to think independently means they need internalize their locus of authority. They need to be able to make their own judgments based on the best available information instead of relying on authority figures for answers [98]. Now I will use the three case studies from Chapter 5 to examine these two aspects of becoming a researcher.

6.1.1 Learning for Transfer: Including both Efficiency and Innovation

Our ultimate goal as educators is that students should be able to transfer what they learn in their classes to areas of human endeavor outside of the class. Learning for transfer has two very distinct elements: efficiency and innovation. Schwartz,
Bransford, and Sears have illustrated the relation in Fig. 6.1 below [97]. If instruction focuses only on innovation, we get a frustrated novice who learns little. The progress of learning is so slow that the learners lose their motivation completely. If instruction focuses only on efficiency, learners become what Schwartz et al. term “routine experts.” It is easy for a routine expert to solve a problem that is similar to what he/she has seen before. However, when facing a novel problem, it is difficult for him/her to break from the familiar routine and to think out side of the box. Schwartz et al. suggest that instruction that fosters both innovation and efficiency may lead to adaptive experts. With a combination of both efficiency and innovation, adaptive experts will be able to learn in new and novel situations and come up with ways to solve unfamiliar problems.

In summary, instruction that includes both innovation and efficiency is the key to fostering the type of transfer Bransford and Schwartz term “preparation for future learning.” [13]

For graduate students, being a routine expert can only help them to solve similar problems to those they’ve learned. To transition from students to researchers, physics graduate students will also need to have developed adaptive expertise to help them find their own way when confronted by novel problems. Doing research means finding answers to unsolved and novel problems, it is not the same as following a set procedure to a certain outcome.

Bransford and Schwartz have pointed out that the reason most cognitive researchers find little evidence of transfer is due to the way they assess it. Most researchers used sequestered problem solving (SPS) where the subjects are sequestered
in a “resource-poor” environment during the test in order to avoid possible “contamination” [13]. Unless the subjects happened to have encyclopedic knowledge of the target domain, it is almost impossible for transfer to happen. They suggested using preparation for future learning to assess transfer. Instead of keeping the subject away from any outside information, they suggest that subjects should be placed in a “resource-full” environment to measure if they can learn in the new situation.

From the interviews, Darren provided us with a keen insight into this distinction when he pointed out that timed exams and quizzes in the core courses did not in any way resemble the process of doing research. Indeed, most physics core course assessments are summative and they often take the format of sequestered problem solving. This kind of assessment requires students to adopt a very different type of learning approach from the “innovation” [97] that is needed for PFL to take place.
In summary, I suggest that the case studies we have seen all point to the idea that sequestered problem-solving environments seem to promote efficiency at the expense of innovation. Innovation can only happen in a resource-full and time-unconstrained environment where people feel free to make mistakes and fail before they succeed. For example, Charlie studied the solution when he did his homework, while Darren changed his learning approach towards Quantum Mechanics. They are both examples of the result of efficiency-focused assessments.

In addition to classroom efficiency, Irvin clearly focused his learning on linear problem solving. I suggest that this is an approach he adopted in order to do well in SPS-type assessments he encountered in his physics courses. His expectation for doing research is the same as classroom learning, namely, he expects to solve problems that have clear procedures and possible answers. However, as I have suggested, we can think of doing research as learning in a new field where the answers are not known. SPS-type transfer studies have shown that knowledge transfer under these conditions rarely happens [13].

The kind of problem-solving skills that Irvin describes in his interview show that his learning was only focused on the efficiency dimension, which makes him a routine expert in Fig. 6.1. While the types of thinking skills and willingness to persevere described by Brian in his interview closely match the adaptive expertise, which combine both aspects of innovation and efficiency in Fig. 6.1.

Irvin only enjoyed solving problems when he knew how to do it. He appeared to be confident and well-trained in the efficiency dimension of solving physics problems for the courses but unconfident in the innovation dimension. Schwartz et al. have suggested that “efficiency-oriented practice is often about ‘problem elimination’ rather
than about in-depth, sustained problem-solving.” Because most physics course assessments focus on efficiency (timed exams, problems similar to textbook examples), Irvin went through graduate level courses successfully developing his efficient problem-solving skills. However, doing research means solving a novel problem where routine procedures might not always help. When Irvin is faced with real research problems, the unsolved problems, he struggled to find a path on his own.

By contrast Brian had a complete and well-structured undergraduate research experience. When he learned about doing research, his learning focused on both efficiency and innovation. The students in that research group were given relatively simple tasks, so they didn’t become frustrated novices. At the same time, they were given opportunities to decide how to conduct the research, which give them the chance to be innovative. The combination of learning in both dimensions made Brian an adaptive expert in doing research. Even though he was only a first-year graduate student, he had full confidence in his ability to direct a research project and to face any difficulty in doing research.

In a study of young children, Martin and Schwartz found that when teaching children fractions, efficiency-first instruction (path A in Fig. 6.1) can get the children to learn more quickly in the beginning [99]. When the same children faced a new situation where they needed to learn new strategies in order to solve a novel problem, the children who went through the innovation-first instruction (path B in Fig. 6.1), eventually caught up to the efficiency group and did better at the end. The innovation group also had a better retention rate, remembering what they had learned. In addition, more children from the efficiency group went back to their old routines after they had learned the new strategy.
Their research suggests a similar story to what we have seen with the graduate students. It appears difficult to foster innovation from a base of efficiency. The case of Brian who has become a successful researcher contains clear evidence that efficiency and innovation developed concurrently in his learning experiences.

Irvin had finished all the graduate level courses before he started working on research. On the contrary, when Brian started doing undergraduate research, he hadn’t taken most of undergraduate physics major courses. Naively, one might expect that Irvin should perform better on doing research since he had more physics knowledge (compared to Brian) to transfer to doing research. In reality, Brian had more confidence that he was able to do independent research while Irvin was not comfortable with making decisions without his advisor’s help. The comparison of Brian and Irvin shows us that physics course training does not guarantee students will become confident researchers. Most of physics courses focus more on the efficiency dimension, while innovation is a very important element for doing research. Comparing the learning of Irvin and Brian, Irvin’s learning path is “efficiency first” (path A), while Brian’s learning was more of a mixture of innovation and efficiency at the same time (closer to path B). This could be the key to their different attitudes toward doing research.

6.1.2 Learning to Become Future Researchers: Internalizing the Locus of Authority

In their interviews, both Charlie and Irvin displayed evidence of an external locus of authority. This means that they believed that knowledge comes from external authority figures and that those authority figures also hold the power to evaluate and direct their learning. Their belief of not being in charge of their learning made
them passive learners who relied on external forces to motivate them to learn. On the contrary, Darren had an internal locus of authority. He was a self-directed learner who was motivated and enthusiastic toward his own learning. His awareness of his own learning process also made him an active learner who was always self-driven toward deeper understanding.

Darren gave a possible reason why students view classroom learning as passive receiving.

[Prof. Q] doesn’t want to just give us the answer, that’s not going to help us. So how is he supposed to help us since he already knows the answer? It’s very different from research. In research, neither of you know the answer, it’s kind of like you’re both on the same end trying to figure things out. — Darren

In the traditional classroom setting, professors are the authority figures. They are there to deliver correct information and set the bar for the grades. Also the materials taught in the courses are generally well studied so that most students, like Brian, view knowledge for the courses as absolute knowledge. Then there is no need for students to develop the ability to evaluate the information received in the classroom.

In the classroom, instructors are expected to know the answers to everything. They are there to show students how to reach the other end. In the research setting, no one knows the answer, including the advisor. Both students and the professors are at the same end, they are partners, trying to figure out the path together. This fundamental difference makes it more difficult for classroom instruction to adopt the apprenticeship model. In addition it becomes difficult for students to learn the important skills they need to do research.

In some cases, for example Irvin, students transfer their beliefs about knowing from the classroom setting to research setting. They have difficulty taking on the
active role of being a researcher. They still rely on external authority to evaluate their progress and show them the way.

Brian was a good example of how the learning environment had a definite effect on his epistemological development. During his undergraduate research, he was treated as a legitimate participant, so he had a chance to develop self-authorship. He viewed himself as a researcher who would decide the research direction and also be able to evaluate both his own and other researchers’ work. Brian had developed an internal locus of authority that gave him the full confidence to perform research by himself. While in the classroom, he turned into a passive learner who did not see any point in directing his own learning. Since there is an instructor in the class, he expected to be provided with information and didn’t bother to make his own judgments.

To provide students with a learning environment that will promote an internal locus of authority in the classroom setting might appear to be difficult. To help students develop the evaluation skills, using formative self-assessment as course assessment, may give students the chance to practice how to evaluate their work and make appropriate judgments. Adopting cognitive apprenticeship into instruction may help students learn to construct knowledge with plenty of scaffolding. This would also narrow the gap between taking classes and doing research for the graduate students.

6.2 The Transition from Student to Teacher

Another role graduate students need to adopt is that of teacher. Although some of the graduate students might not take a teaching job in the future, they can still benefit from learning instructional skills.
The physics department needs a significant number of graduate students to teach as teaching assistants. The data I have gathered shows that graduate students don’t appear to think they have gained much from their teaching experiences. A lot of them become unmotivated to teach and only fulfill the minimum requirement. If we can provide graduate students effective teaching training, and have a program to support their instructional development, the undergraduate students who are taught by the graduate teaching assistants may benefit from better education as well. At the same time, graduate students may be able to develop the confidence to teach and have a better chance to become more effective physics faculty in the future.

The two important elements of becoming better teachers are:

1. Graduate students should adopt a teaching/learning model that is aligned with current research on successful, effective instructional practices that promote learning.

2. Graduate students need to have adequate pedagogical content knowledge [30]

Currently some of the graduate students still hold the belief that teaching and learning means the transmission of knowledge from instructor to learner. Adopting a teaching/learning model that is aligned with current research, not only would change their approach to teaching, they would also benefit from becoming active learners as students. Learning pedagogical content knowledge will require graduate students to put in time from their already busy schedule. However, having knowledge of the instructional strategies that help students learn would also make them better instructors and hopefully help them feel less frustrated with their teaching. In this
section I will use the interview results to discuss why these two elements are important and what are the possible ways to approach them.

6.2.1 Adopting a Constructivist View of Learning

In the classroom setting, Brian adopted the transmission/reception model for teaching and learning. As a student in the classroom, he expected to be fed information. He focused his learning on memorizing and took a passive role in his studies. He transferred the same belief into his classroom teaching. He focused his teaching on presenting the materials and expected students to get it by passively listening. On the other hand, he learned how to do research by participating in a research project. His research group gave him a chance to learn by figuring things out by himself. When he ‘taught’ the new incoming students how to do research, he tried to use the same model: namely to guide students through the process of discovery.

This case study illustrates how graduate students’ beliefs about teaching and learning influence their choice of teaching approach. Luft’s study [18] had a similar finding. In her study of graduate teaching assistants in science, she found graduate TAs focused on delivering correct ideas to students even when they were working in an active engagement environment such as a group-work setting. Graduate teaching assistants generally projected their own learning expectations as if they were in the place of students they were currently teaching — They focused on presenting the material as clearly as possible to the students rather than letting the students figure out things with the TA as a guide.

Another significant point about Brian’s case study is that he failed to transfer his beliefs about teaching and learning from the research setting to the classroom
setting. He compartmentalized his beliefs based on the environment he perceived. This suggests that in order to have instructors/teaching assistants adopt more learner-centered instructional practices, it is necessary to provide the environment for them to see the need of doing so. It might also be important to let them experience the active learning process in the classroom setting, so they would be more likely to transfer the constructivist view to their teaching.

6.2.2 Exposure to Alternative Instructional Strategies

From the interviews, graduate students were hesitant to suggest using alternative instructional practices in the graduate level courses while they were willing to use them in the introductory physics courses. One possible reason is that they had seen the research-influenced curricula being used in the introductory courses but only experienced very traditionally taught graduate level courses.

Other than group work, physics graduate students know very little about alternative instructional strategies. They have little chance to learn about pedagogical content knowledge. They mostly used other graduate teaching assistants as their resource of instructional knowledge.

There are programs specific designed for better preparing physics graduate students to be teachers. The Preparing Future Physicists (PFP) was designed to scaffold graduate students’ professional development as educators [3]. Graduate students were encourage to participate in a voluntary program with weekly seminars in which they learned about possible teaching environments in the future and also some practice-based activities to develop useful teaching skills. The program also provided physics
graduate students adequate pedagogical content knowledge through a graduate course of education research.

Providing physics graduate students with an apprenticeship-like instructional training program, they would be able develop professional instructional skills and be more likely to adapt new educational research findings into their future teaching.

Future physics faculty come from current physics graduate students. Physics graduate students with better instructional training not only would be better teaching assistants now, they would also become the future physics educators responsible for the future of physics education.

6.3 Fostering Legitimate Peripheral Participation

It is clear from the interviews that legitimate participation is one of the most important elements for students to learn to do research. Currently, graduate students learn to do research as apprentice researchers. The successfulness of their research training seems to depend on the kind of participation they are engaged in.

It might be difficult, if not impossible, for the physics graduate program to monitor each research group and research advisor on their daily activities to ensure the quality of graduate students’ participation. There are however, other department-wide programs that can provide scaffolding that graduate students need to practice research-like activities in safe learning environments.

In this section I will use the OSU graduate colloquium as an example to illustrate how small changes can make a big impact to encourage graduate students to engage in research discussions and feel like legitimate participants.
6.3.1 Graduate Colloquium

In 2006 the OSU physics department started a graduate colloquium. This is not the first time that graduate students gave formal talks. These talks used to be constituted as the summer ‘ice-cream’ seminar. In these seminars, upper-level graduate students gave talks about their research to the rest of the graduate students. I observed some fundamental differences between the ice-cream seminar and the graduate colloquium that replaced it in 2006.

The summer ice-cream seminar was arranged as a seminar course. Students could take it for credit. Upper level graduate students were encouraged to present their research results in the seminar. All the graduate students were encouraged to attend. The seminars were run by a professor. The professor arranged the presentation schedule and also facilitated the seminar. The seminars gave upper-level students a chance to practice giving a formal presentation, and let the rest of students learn about other people’s research.

In 2006, the summer seminar was replaced by the graduate colloquium. The new colloquium is run by the physics graduate student council, which is run by graduate students. The colloquium is given in the regular quarters, and any students can volunteer to give a talk. The presenters are asked to give talk on a well-known topic in their research field. Another unique feature is that no faculty member is allowed to attend the graduate colloquium.

I attended every graduate colloquium in the first year and found it quite different from the previous summer ice-cream seminar or the regular colloquium. During the graduate colloquium, the audience (graduate students) asked many more questions compared to the summer seminar or regular colloquium. Additionally, the types of
questions asked were not limited to basic clarification questions. It was quite often, almost every graduate colloquium I attended, that the question and answer would turn into a group discussion. The speaker was not the only person answering the questions anymore. A lot of students would try to provide their point of view from their own research field. On the contrary, in the previous summer seminar, there were fewer questions asked and the majority of the questions were superficial clarification questions. Sometimes the professor would ask a question if no one had question.

Unfortunately, I was not able to get the colloquium videotaped in order to perform a detailed analysis. I believe this would have been a good chance to study the relationship between student group interaction and the environmental factors that support or hinder that interaction.

I hypothesize that the presence of a professor causes graduate students to behave differently. In the regular colloquium or summer ice-cream seminar, since there are professors in the room, students worry that their questions might appear stupid, causing them to think twice before they ask the question. In the graduate colloquium, since there was no professor attending, and the speaker is a graduate student as well, the graduate students do not view the speaker as an authority figure. They feel free to challenge the speaker’s ideas and express their own ideas. Since the speaker is just a graduate student, it is possible for the speaker to make mistakes. Every question can turn into a long discussion. In this environment the graduate students are participating something very similar to a research discussion.

On the other hand, in the regular colloquium, the speakers are well known researchers. When students view them as authority, it is impossible for them to challenge the speaker’s ideas. Even for the summer seminar, when the speaker was student
as well, with a professor in the room, it seemed to remind students that they are only novices in their research.

The graduate colloquium seemed to be successful in generating discussions across research fields. The speakers were asked to present a talk for 30 minutes. I never saw a speaker able to deliver the talk without being interrupted. With the questions, the colloquium normally ran over an hour. Generally the discussion continued way after that. Since the graduate colloquium was not a course any more, no one was taking it for credit. The good attendance at these colloquiums suggested that graduate students were interested in attending those talks. One possible future study is to get both the graduate colloquium and regular colloquium videotaped to analysis the quality and quantity of the questions asked by the graduate students. This would be an interesting research project to illustrate how graduate students behave differently due to their self-perceived legitimacy.

6.3.2 Question Asking

In the interviews, two of graduate students talked about how they felt uneasy in asking questions, especially when they asked the professors.

Sometimes I am embarrassed, but it’s hard to admit, for me it’s hard to admit that I don’t know or I don’t understand. — Henry

Both of them felt uncomfortable in admitting they didn’t understand something when they thought others expected them to know it. They both agreed that it is easier to have discussions with other graduate student(s) or postdoc(s) than a professor. Gary talked about the reason that he felt more comfortable in talking to the other graduate students even though graduate students might not have the correct ideas.
Yes, because, with the graduate students I’ve dealt with, they have a measure of reserve in their attitude toward the correctness of an answer; they don’t insist that their solution is the right solution. And having an incorrect but well-reasoned solution helps me feel more confident in discussing with those who have a more correct solution. — Gary

It seems like the issue here is that Gary wanted to develop his own understanding through discussion with other people. When he was talking to the other graduate students he was able to express his own ideas and maybe reject other students’ ideas if he disagreed with them. On the other hand, when he was talking to a professor, he hesitated to hold a different opinion from the authority figure.

Graduate students should be in the process of developing self-authorship. From above two examples we can see how graduate students behaved very differently due to the presence of professor or not. In practice, the goal of helping graduate students start to view themselves as legitimate researchers and develop an internal locus of authority is undoubtedly more challenging than simply keeping the professors out of the room. Future research needs to examine how we can structure learning environments to help physics graduate students internalize their locus of authority and develop confidence in their own abilities.

6.4 Instructional Implications and Future Research

Physicists believe that mathematics is the language of physics. In the case of graduate physics core courses, students found that the physics was lost in translation. From the interview study, 1) students lost sight of the bigger picture, and 2) an over-emphasis on mathematical details made students less motivated to learn.

Almost all the graduate students I interviewed suggested putting more emphasis on the bigger picture in the courses. They said that they would be more interested
in learning if there were more connections to real world applications. They needed
to understand what they learned in class was not disconnected facts, but that there
was a coherent picture behind all the little details they were learning. What’s more
important, they also needed to see the bigger picture behind what they were doing
in the classroom learning, teaching, and doing research. They needed to see the
connections between what they learned, what they taught, and what they researched.

6.4.1 Making Connections between Learning, Teaching, and
Research

One of the graduate students, Gary, talked about how participating in a research
project made him appreciate the course materials more.

I think I learned to value the things taught in courses more because I
saw how much effort is needed just to answer really specific questions. —
Gary

Here Gary showed how his research experience helped him appreciate learning
in the classroom more. Also in Brian’s case study, we saw how Brian compartment-
talized his beliefs about learning into classroom setting and research setting. Both
cases show that classroom instruction needs to incorporate more research elements to
help students realize that what they are learning in the classroom is not completely
detached from up-to-date research.

Other than making connections between course materials and physics research, it
is also important to have students practice research skills in the classroom. One way is
to include a research project into the classroom learning. Another way is to have stu-
dents learn the physics content in the way similar to the way researchers discovered it.
The courses can include activities like having graduate students conduct a literature
search on some physics topic, engaging students in debate on different hypotheses, and reviewing past research papers with newly discovered evidence. Through the process, students would be more motivated in learning the material while they are practicing useful research skills. An OSU physics professor, Dr. Bruce Patton, attempted to teach graduate level Electromagnetic Field Theory with an inquiry approach [100]. In the last quarter of the course, students in groups were given the opportunity to study a current research topic and then prepare a week of material to teach to the rest of the class. In the process, students learned a brand new topic on their own with help from the instructor, and they practiced making lesson plans and coming up with homework problems.

In this case, students had a chance to do some research on their own and practice teaching at the same time. They learned through studying existing research and taught what they just learned. Such an approach can close the gaps between classroom learning, teaching, and research. More detailed systematic research on alternative instruction methods in physics graduate level courses is also needed. It is important to study the effectiveness of the alternative instruction. It is also important to gain a better understanding of the mechanisms behind each instructional strategy. Understanding these mechanisms will help us better understand how each innovation affects student learning and further help on understanding of intellectual development as researchers.

6.4.2 Making Graduate Students Legitimate Participants in the Research Community

From the cases of Brian and Irvin, we can see how Brian was better trained to do research when he learned in an environment in which he was treated as a
legitimate participant. In the case of Irvin, his early research experiences led him to feel unqualified or poorly qualified to participate in research. At the time of the interview, close to finishing his degree, he still relied on his advisor to provide direction. I have also discussed how graduate students behaved very differently in the graduate seminars when there was no professor attending. All these cases suggest one important ingredient in graduate student education: making graduate students legitimate participants in the research community is the key for them to transition from students to researchers.

In Chapter 2 we examined the list of differences between traditional and alternative instructional practices suggested by Dancy and Henderson [25]. In Table 6.1 I will propose a similar list for instructional practices for training graduate students to become researchers. This list incorporates several PER-based instructional ideas. First, to make them legitimate participants in the research group, graduate students should be treated as researchers. To encourage them to have their own opinions, their opinion should be valued and discussed. In order to let students develop self-authorship, they should have a chance to be responsible for at least one research project and take the lead on moderating important decision-making. Finally, to scaffold this process of learning to become researchers, there need to be some sort of formative assessment to provide feedback to help students to improve. Ultimately, graduate students need to have the ability to evaluate any research they encounter in their field. That is, they need to be able to self-assess their own work, so they can monitor their own research progress. They also need to be able to evaluate other researchers work. One reason is that the research community relies on researchers to
monitor each other’s work. But more importantly, a researcher needs be able to make his/her own judgment about all the information he/she encounters as a researcher.

<table>
<thead>
<tr>
<th>Advisor-directed research</th>
<th>Student-directed research</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advisor-student relationship</td>
<td>Researcher-researcher relationship</td>
</tr>
<tr>
<td>Provide direct/clear instruction</td>
<td>Encourage or support student discovery/forming their own ideas</td>
</tr>
<tr>
<td>External Motivators (student focus on getting the work done)</td>
<td>Internal Motivators (student understand the reason behind each decision that is made and its purpose in the bigger research picture.)</td>
</tr>
<tr>
<td>Advisor evaluates research progress</td>
<td>Students expected to self-evaluate and be able to evaluate others</td>
</tr>
<tr>
<td>External definition of success by publication, awards etc. . .</td>
<td>Success defined by research achievement in terms of growth of understanding of the world</td>
</tr>
<tr>
<td>Major decisions made by advisor</td>
<td>Students make decisions by reviewing all the available information and contributions from other researchers.</td>
</tr>
<tr>
<td>Explicitly instruct students in research technique</td>
<td>Explicitly model the cognitive thought process behind the research technique</td>
</tr>
</tbody>
</table>

Table 6.1: Instruction practices for training students to do research

Of course, the actually practice of training students to become researchers is much more complex. The details of how to provide scaffolding during instruction or how to assess the effects of this instruction would require further research. A longitudinal study on graduate students learning to become researchers is needed to better answer how to put this theory into practice.
The OSU physics department is on the right track in providing students opportunities to participant in a “safe” situation. Having a graduate colloquium is a good start. It is also good to have a special question session with the regular colloquium speaker for the graduate students only. These kind of activities give students a chance to speak out without worrying about appearing unknowledgeable. The next step is to create an environment where graduate students feel able to behave like that even when the professors are present. But we still need more understanding of the mechanisms behind helping graduate students develop the confidence to view themselves as researchers. Studying graduate students behavior in these special-designed environments, like graduate colloquium, might help answer questions about how students develop into researchers on the emotional and motivational level. A study of the type of questions students ask in the regular colloquium and graduate colloquium might further reveal the link between graduate students behavior and the environment they perceive.

6.4.3 Making Graduate Teaching Assistants Legitimate Participants in Teaching

Suggested problems to go over, great. Three hour meetings on alternative ways to solve the problems for the students, not so great. Take ten minutes to explain the problem, but if your TAs can’t properly do a 112 problem after a ten minute review on the subject, then either the problem is way too hard or they shouldn’t be teaching. Even if they don’t do anything different. If you allow them the flexibility to actually, you know, do things themselves, go the extra mile, sometimes they even do.
— Lance

In general, physics graduate teaching assistants are motivated to teach well. Unfortunately, when they are not treated as legitimate instructors, they lose the motivation to teach. As Lance said in this quotation, the teaching preparation meetings
spend the majority of the time making sure teaching assistants understand the problem, and this is neither effective nor practical. It also sends the graduate TAs a message that they are not qualified to teach — this can further demotivate them.

As a first step, I suggest that the focus of those meetings should be moved away from the details of problem solving. Most graduate students have sufficient physics knowledge for the introductory level courses and if they need help they know where to find the resources. In those meetings, other than necessary course business, the meeting should focus on a discussion of possible student difficulties. This will encourage teaching assistants to provide input based on their teaching experience. This should help graduate students to be motivated to teach and keep them interested in learning about teaching.

During the interviews, one of the graduate students also suggested providing a physics education course for the general graduate students who are interested in learning how to teach. A systematic course providing relevant pedagogical content knowledge would further help graduate students become successful teachers. Possible education course materials are available from several research programs like Preparation for Future Physicists.

### 6.5 Final Words

The data I have gathered has both strengths and limitations. The student population from which this study was drawn came mainly from one university. Uniform features of the OSU physics department environment may result in student behavior that may be very different as compared to another institution. For example, it is clear from my data that OSU physics graduate students lack freedom in how and
what they are allowed to teach. At another university, students might be given more freedom in how they engage in teaching. What we can learn from the restricted sample is what does not work, but, in the domain of developing future teachers, there is little evidence from my sample of what does work. On the other hand, the physics research environment is so highly dependent on the advisor that it is almost certain that we will get a good sample of different research experiences that are probably generalizable to the physics graduate student population as a whole. Indeed, this seems to be the case with my sample of 15 graduate students. I have been able to identify both students who have succeeded and those who have failed to develop self-authorship as researchers. The contrast between these examples has allowed me to develop some very clear ideas about how one can design the research environment so as to encourage graduate students to develop into successful researchers.

As physics education researchers, we need to study the connection between how graduate students learn, how they teach, and how they conduct research. The graduate physics program is a complex dynamic system. Understanding these connections will further help us understanding the mechanism of each element of the program. This will help us understand ways in which we can restructure the physics graduate program to make more successful physicists in the future.
APPENDIX A

THE INTERVIEW QUESTIONS

This appendix lists the interview questions. Since the interview was semi-structured, these are guideline questions that represent starting points for further follow-up questions that were specifically tailored to the initial responses of each interviewee.

A.1 General Information

- How many years have you been in graduate school? (If the person was transferring from another school, I would ask how long they were at the other institution.)

- What courses have you taken? Both core courses and advanced courses.

A.2 Learning in the Courses

- What is your favorite course? What course you don’t like the most? Why?

- Which course did you learn the most from?

- What did you try to learn from the courses? How did you study for the courses?

- What did you learn from the core/advanced courses?
• Describe a course that you would like to see in the physics department that you think is missing from the curriculum.

• How should the courses be modified?

• What did you learn from the core/advanced courses that is useful in your research? (For upper level graduate students only.)

• If you can change the way the courses are taught how would you change them and why?

A.3 Teaching

• What courses have you taught? How is your teaching experience?

• What did you want your students to learn from the course? What did you do to make sure they learned it?

• What would you do differently if you can teach any way you like?

• In the future, when you are a professor, how would you teach an introductory physics course? How would you teach a graduate level core course?

A.4 Research

• What is your research about?

• How and where did you learn the skills you need for doing research?

• Do you use anything you learn from the core/advanced courses in your research? What is it?
• What do you expect from your advisor? Is your advisor doing enough or not enough?

• Did you have any research experience in undergraduate? When? Where? How?

• Did your undergraduate research experience help you on your learning in any way?
APPENDIX B

ANALYSIS OF TWO ADVANCED STUDENTS’ RESEARCH DESCRIPTIONS

B.1 Research Student 1

I run a CREAM experiment which is cosmic ray energetics and mass, um, it’s a balloon experiment that flew, has flown twice over Antarctica for a total of seventy days, uh, which is actually quite phenomenal. The instrument itself consists of four or five sub-detectors, depending on how you count. The first one is a timing charge detector that my advisor, [Dr. J] built. It obviously is designed to measure charge, but it’s also, it’s a layer, two layers of scintillator, um, so the signal that you actually get out from scintillator to PMT [photo-multiplier tubes] to electronics to computer. So that computer-read signal that we actually have is obviously a function of charge and energy. Then below the timing charge detector is a transition radiation detector, TRD, um, that gives you tracking, because it’s lots of tubes.

Which is crucial in the experiment for, um, doing things like path-length corrections. If a particle takes a longer path through your scintillator, you get more light, and that’s not... that’s true, but it’s not what you want to measure. So you correct for things like that.
It also gives you something that is, um, a function of charge and energy. Likewise, the silicon charge detector below that, gives you charge, well, charge an energy, and the calorimeter, it’s a thin calorimeter, um, gives you charge, energy, mainly energy, and a little bit more tracking, but it’s not as good. So, by plotting, by... basically calibrating all of the instrument, all of the sub-detectors, and then plotting each sub-detector against another one, you find bands of events with a given charge at a given energy.

So why do we even care about that? We care because CREAM measures charges all the way from protons through, um, iron, which is basically the total spectrum of cosmic rays, um, in the energy range $10^{12}$ to $10^{15}$eV. That is actually a crucial energy range. $10^{15}$eV is... $10^{16}$ish, somewhere in there, is the region that is known as the ”knee”. So, from about $10^{8}$ eV to the knee, you have what, the flux of cosmic rays over energy is essentially a power law, it goes as $e^{-2.6}$. At the knee it changes to about $e^{-3}$. So CREAM is measuring right at that break in the spectrum, and it’s measuring it for all of the particles so that we can really get a handle, so that we can actually measure how they all change, fill in that gap, because we basically have lots of measurements from other balloon-based experiments below about $10^{12}$ eV, and lots and lots of measurements from ground-based experiments that are above $10^{16}$ eV. So right at that knee, there’s a gap where the detectors we have have limitations which prevent them, have prevented them in the past from measuring that region. So we’re going to fill in that region, which is going to be crucial for studying the shape of the energy spectrum. That information will hopefully give us a much better handle on where cosmic rays come from.

We have hypotheses for their sources.
The ones that have energies below the knee are probably from supernovae, but that’s not actually been proven yet. There’s no definitive evidence, so this will help give us definitive evidence, both of their source in supernovae, their acceleration mechanism, which is supposed to be second order Fermi acceleration, which is basically shocking, um, and propagation conditions through the galaxy. So that... Then you can say, okay great, well why do we even care about that? Well, we learn more about supernovae. We learn more about shocking mechanisms which are a big part of everything past... anything that happens after the big bang gets energy, usually because of some form of shocking.

As far as I know there aren’t so many stochastic energy processes. There are the equilibrium processes like stellar synthesis. But if you really want to get things up to high energies, which is, quote, unquote, the “interesting region”, you tend to use shocking mechanisms.

So you learn about shocking. And the more we know about the interstellar medium, and if we can actually study the highest energy cosmic rays, we learn about the intergalactic medium. The more we know about that, the more we characterize the universe. The better we characterize the universe the better we have pinned down the parameters that go into understanding cosmology. So it really has tendrils branching out into all of astronomy and cosmology and astrophysics. So hopefully that wasn’t more that you wanted.
B.2 Research Student 2

But where am I going with my thesis also, sort of, a different science thing is to use gamma ray bursts to test the Lorentz invariance.

And so the idea that the speed of light is a constant, it turns out you can get a good test of this because gamma ray bursts are far away. And so that’s a piece of knowledge that’s you know, not just core courses, but, you know, first year physics, the idea that the speed of light is a constant, and we want to test this because this is a fundamental principle of physics...

So suppose the speed of light is not a constant, that is, it depends on energy.

Some people predict that quantum gravity makes the speed of light depend on energy. It doesn’t matter, it’s a fundamental principle, you should test it, quantum gravity, or no quantum gravity. So suppose a high energy photon goes slower, it doesn’t matter, it could go faster, it could go slower. Suppose you have two photons that start at the same place at the same time, but one’s faster and one’s slower. Well, if you’re very very far away, then one of them gets to you first, and the other one gets to you later. And now the speed difference is very small, so you want to be very very far away. But the other thing you also want is a big energy difference, because the bigger the energy difference,
the more the effect. And so what’s nice about a gamma ray burst is that there are pulses of gamma rays, and, that is, if you’re right beside something, to you, a high energy guy and a low energy guy happen at the same time, they come out of the pulse at the same time, but if one of them is very far away, then that pulse will look to be spread. That is, the high energy guys, let’s say, will always come later, for example, than the low energy guys. So you look for something like this, and that’s a test of a fundamental physics principle, a basic physics principle, and so that is a piece of science that’s related to whatever course,

but it’s not like, uh, you know, some specific equation thirty-two out of, you know, whatever Jackson or something. There’s also a lot of physics I haven’t gotten into related to gamma ray bursts, how do gamma ray bursts work, there’s plasmas involved and magnetic fields. Presumably there’s a large explosion of some kind, how do you understand these things, there’s high energy, there’s particle acceleration. All of those things I haven’t touched because I’m working on this, and this is important because we want to be able to do this for a number of astronomy reasons. So that’s the physics that over the next year I’m gonna be focusing on. It’s Lorentz violation, and then, you know, hopefully by November or so I’m done with this whole algorithm business. There’s always a possibility that there’s an intrinsic delay, but what you can do is, there are gamma ray bursts that are close and those ones you will not notice any difference. There’s no time delay because they’re close enough, and then what you have to do, you’re right, there’s a number of assumptions. You have to say, okay, well the one that’s far, do I believe it’s the same type of object? Can I understand a certain amount of physics so that I can say, well to within some errors, I can put a bound on the constant of the speed of light. And you’re right, there’s assumptions, but, you know, there’s always going to be some assumptions.

But you can calibrate with the close guys and then you can use the far ones away to do this task.


[34] D. B. May, *How are Learning Physics and Student Beliefs about Learning Physics Connected? Measuring Epistemological Self-Reflection in an*


