Processes of problem-solving and instructional change in physics

by

Dina Zohrabi Alaee

B.S., Payame Noor University of Tehran, 2008

AN ABSTRACT OF A DISSERTATION

submitted in partial fulfillment of the
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Abstract

This research presents an investigation of how students solve physics problems and how physics instructors approach changes in their teaching. In particular, the first part of this dissertation focuses on three major projects looking at students' processes of problem-solving in upper-division physics courses. The second part focuses on the processes of instructional change.

In the first project described in part I, I discuss the clusters of resources that emerge when upper-division students write about electromagnetic fields in linear materials. I use a resource theory[1–3] perspective to describe the ways students link pieces of information (or resources) to form more complex ideas, improve their understanding, and solve physics problems. The evidence shows that students benefit from activating resources related to the internal structure of the atom when thinking about electric fields to complete their mental model.

Physics as a discipline embeds conceptual meaning about the physical world in mathematical formalism. In the second project, I use Sherin's symbolic forms theory[4;5] to present an analysis of the different physical meanings associated with the equal signs across a physics context. Sherin's symbolic forms framework links mathematical equations to intuitive conceptual ideas. I delineate types of equal signs as used in five undergraduate level physics textbooks and develop a categorization scheme. Six distinct meanings are identified: causality, balancing, definitional, assignment, hybrid, and calculation. After considering five physics textbooks, I then analyze students' solutions in their written homework in an upper-division electrostatics course and compare them to textbook solutions. In doing so, I am able to look for patterns and compare the ways students use the equal signs to the textbook solution manual.

In the last section of Part I, I examine students' epistemological framing[6–9] when solving physics problems as a group. I analyze videos of students solving electrodynamics problems. I consider two epistemic frames which are common in students' discussions during problem solving in group: sense-making and answer-making. I first characterize the markers of each frame, focusing on analyzing students' group frame. Then, I present a pair of examples that show how often students transition between these frames. I notice moments that students change their attitude towards the problem to move forward in their activities. While there are many ways to view how students practice physics, the results of this project provides deeper insight into students' problem solving processes in an upper-division course.

In Part II, I use phenomenography[10] as a methodology to explain how physics instructors approach making changes in their teaching and the different kinds of support that they would like to have. The purpose of phenomenography is to describe the qualitative variation in people's experiences. For example, what are the ways in which physics instructors think and talk about their teaching practices?

Our phenomenography study explored six different major categories: how instructors approach their teaching, their motivation to make changes, resources that they have used, how they have implemented those resources, challenges they experience during a semester, and their attitudes towards implementing new changes. We ultimately aim to use our findings to redesign the PhysPort website[11].

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Dedication

This thesis is dedicated to the memory of my beloved mother, Shookoo Zare.

Part I

Processes of problem-solving among upper-division students

Chapter 1

Review of related literature and studies for Part I

1.1 Map of dissertation

Physics education research (PER) has produced a large body of literature that describes how students learn, understand, and approach solving problems in physics courses[12–20]. Problem-solving has long been seen as an important aspect of the learning of physics.

The work described here is separated into two different Parts (I and II). Part I describes three major projects, around process of problem-solving in upper-division physics courses. I drew from different theories related to knowledge in pieces (KiP) theories to explain students' problem-solving activities[1–6]. Within Knowledge in Pieces (KiP) there are a family of related theories focusing on structure and dynamics of students' knowledge. Part II is based on the processes of instructional change among physics instructors. This dissertation consists of 8 chapters. In this first chapter, I provide a summary of each three projects and a comprehensive review of previous research relevant to my studies.

Part I contains chapters 1 to 5. In this chapter, I review the literature related to my research questions in Part I around students learning. Chapter 2 describes the first project about student understanding of electric and magnetic fields in materials, as well as the methodology and analysis of students' responses to the problem. Chapter 3 presents an analysis of the different physical meanings associated with the equal signs across physics context. Chapter 4 examines students' epistemological framing, during physics problem-solving in a group setting. Lastly, chapter 5 compares all these three studies and present the conclusion.

Part II contains chapters 6 to 8. Chapter 6 reviews the literature related to professional development and educational change, to answer my research question about processes of instructional change among physics instructors. Chapter 7 describes the research setting and qualitative research methodology in detail. Chapter 8 summarizes how these studies advanced the future research and help professional development designers to develop and build more useful materials and sustain instructors' performance in the classroom.

1.2 Literature Review Overview

1.2.1 Resources and phenomenological primitives

The first project is a nuanced investigation of how students solve problems in an upper-division electricity and magnetism course which looks Specifically at clusters of resources that emerge when students solve a problem about electromagnetic fields in linear materials. This is an important topic to research in science and technology. For instance, dielectrics have numerous practical applications in the home and industry. The development of mechanistic reasoning plays an important role in student understanding, and evaluating understanding in STEM disciplines often involves unpacking the structure of student reasoning.

A significant body of research in physics education has been devoted to improving the teaching and evaluation of electricity and magnetism (E&M) at the introductory level[15;21;22], but less attention has been geared towards upper-division E&M[23–29]. Prior research into students' problem-solving of E&M at the upper-division level has focused on student understanding of specific topics like Maxwell's equations[27–31]. Other research uses E&M as a context in which to study mathematical tools which support physical reasoning[32;33], student identity development[34], or epistemological framing[35].

In Chapter 2, I discuss student responses to conceptual homework problems about linear materials in electric and magnetic fields. I use resource theory[3] (from the family of the knowledge in pieces theoretical perspectives) in order to describe the ways students use prior knowledge – or resources – and link pieces of information to form more complex ideas, improve understanding, and solve problems. As researchers gain more insight into the diversity of student thought processes, patterns in how students use and combine resources help us better understand student learning. I categorize the responses by the students' resource usage and look for changes across contexts.

One theory within the broad family of KiP is about phenomenological primitives or p-prims for short[1;2], which are the simplest, smallest possible grain size piece of knowledge (or resource). Phenomenological primitives are atomistic pieces of reasoning that are abstracted from people's experience. Broadly speaking, a resource is a discrete piece of an idea that a student activates when considering or solving a problem[3].

It is important to note that p-prims and resources themselves are not inherently right or wrong (e.g. *closer means stronger*)[1], and that student difficulties arise from misapplying resources (e.g. it's hotter in the summer because the Earth is closer to the sun). Students build resources throughout their lives and education[36], and they use these resources by activating and linking them to form mental models of complex physical and mathematical phenomena.

Unlike phenomenological primitives (p-prims)[1], resources can have internal structure that is accessible to the user[36;37]. Because resources can be more complex and structured, students can develop resources for sophisticated topics such as diode construction[38], separating differential equations[39;40], or quantum mechanics[41].

Several kinds of resources have been identified. *Conceptual resources* are pieces of knowledge or understanding concepts, such as "coordinate systems"[36] or "activating agent"[1]. *Procedural resources*[40] are actions such as bringing constants out of a derivative[42] or summing forces. *Epistemological resources*[43] are elements of beliefs about the nature of knowledge, such as whether results can be figured out or if they need to be looked up. To solve problems, students coordinate all three kinds of resources, activating connections between conceptual resources and procedural ones to build arguments, as mediated by epistemological resources about the problem-solving they are engaged in. In Chapter 2, I explore which conceptual resources are activated in clusters when students write about polarization and magnetization.

Another characteristic of resources is their plasticity versus their solidity[36]. Solid resources are durable and well established, and their internal structure need not be accessed for use. In other words, they require less justification and can be more easily and readily used and linked with other resources. Plastic resources are unstable and require more elaboration and justification to be used. They are usually new resources for the student, and their connections to other resources have yet to be solidified. More broadly, "stable networks" are networks of resources that are "cognitively nearby"[38], and tend to activate together[36]. In Chapter 2, I also examine how the plasticity of conceptual resources and the networks and clusters of resources students use change with increased conceptual instruction.

Solid networks of resources form students' mental models. Mental models "enable individuals to make predictions and inferences, to understand phenomena and events, to make decisions, and to control their execution. They are incomplete, despite being structural analogues of the processes taking place in the world"[44]. After interviewing students across a wide range of ages and backgrounds, Borges and Gilbert gained insight into mental models of electricity, and found that the more successful and complete the model was, the more microscopic (very detailed) it tended to be[45]. They also discuss students' use of causal agents in their reasoning. They discovered that many of the more incomplete mental models the subjects had about electric current moving through a wire were characterized by the interchangeability of words such as "electricity", "current", and "energy". The subjects knew that a causal agent must come between perceived related events, such as a wire being connected and a light bulb lighting up, and they filled in resources about "something" flowing, without knowing what that "thing" was.

Borges and Gilbert investigated mental models of magnetism as well[45]. Although their discoveries were of mental models of magnets creating magnetic fields, those models may be closely related to the mental models students have of materials subjected to a magnetic field.

Again, the most complete mental models (meaning the ones with the most power in making predictions and inferences about a situation) were also the most microscopic models (very detailed). They also found that the participants interviewed with the most prior experience and formal instruction about magnetism were the only ones who thought of magnetism as a result of micro-currents circling around the atoms in a material that line up to produce a field. They concluded that deliberate instruction can affect students' mental models, noting that "when comparing students' models, the effects of their models are evident, as shown by the vocabulary and the type of constructs they use" [45].

After discussing clusters of resources that emerge when upper-division students solve a problem about electromagnetic fields in linear materials in Chapter 2, I move on to Chapter 3 and investigate the mathematical and physical meaning of equations, Specifically looking at the equals sign.

1.2.2 Symbolic forms

There is a long history of mathematics education research, mostly in K-12 contexts, into students' understanding of mathematical symbols in general, and equality in particular [46–56]. In one of the earliest studies, Behr *et al.* [48] observed that elementary school children consider the symbol "=" as a "do something signal" that "gives the answer" on the right hand side. There is a strong tendency among all the children to view the "=" symbol as being acceptable when one (or more) operation signs precede it.

Falkner *et al.* [57] identified kindergarten students that understood the concept of equality but could not transfer that understanding to algebraic problems. He also found that students often interpreted the equals sign as indicating action (a "do it" sign), with older students gradually recognizing it as a symbol that indicate a relationship.

Knuth *et al.* [58] linked middle school students' understanding of the equals sign with performance on solving algebraic equations. These and other contemporaneous studies focus on the mathematical-appropriate abstractions of equality, using physical systems primarily as examples and illustrations.

Other studies confirm that students across K-12 see the equals sign as primarily an operational symbol and do not have a deeper understanding of mathematical equivalence[51;52;58;58]. Kieran[51] found that the idea of the equals sign as operator is formed before formal education begins and continues throughout high school. This view encourages students to see formulas as knowledge to be memorized and prevents a recognition of the underlying meaning and structure.

Recently, physics education research (PER) has documented student approaches to solving problems in the specific physics contexts[14;16;17;59–61], examining how students form relevant representations to understand and communicate physical ideas to solve problems[62]. In order to translate a problem statement into algebraic expressions, students may encounter many different representations of physics ideas, including gestures[63], graphs and diagrams[64–67], mathematics[4;5;9;68;69], and language[70–72].

Most physics education research on problem-solving has focused on students' conceptual understanding or engagement with mathematical processing[12–14;16–19;73–76], rarely connecting the two. In a review of over a decade of published articles on problem-solving from nine leading physics and science education journals, Kuo *et al.*[76;77] found "no studies that focused upon the mathematical processing step or described alternatives to using equations as computational tools". This is despite the general recognition that the interpretation of mathematical symbols is a necessary skill in developing students' understanding of physics[78–80].

In the context of physics, Tuminaro *et al.*[81] gives a broad theoretical framework to enable us to understand students' mathematical reasoning while solving physics problems. Researchers have found that students tend to struggle when combining mathematical operations and conceptual reasoning about real world physical phenomena during problem-solving[82]. Physics as a discipline embeds conceptual meaning about the physical world in mathematical formalism. How meaning is associated with symbols depends sensitively on context, and physicists can shift meaning through symbolic manipulation.

More recently, Uhden *et al.*[83] used the term of "mathematization" to develop a model for how mathematics is used in physics education. A core feature of understanding students' mathematizing in physics is identifying how students represent concepts symbolically, verify solutions, and connect them to the physical world.[84–87].

In Chapter 3, I use different theories related to knowledge in pieces (KiP) to describe conceptual and cultural meanings of the equals sign across physics contexts. Sherin[4;5] proposed the *symbolic form* as a cognitive mathematical primitive (p-prims) that associates physics conceptual meaning with mathematical symbols in order to understand "how students understand physics equations." Figure 1.1 lists the different symbolic forms that Sherin identifies. He observed that students associated various conceptual ideas with mathematical expressions as they solved problems and identified numerous different forms. We took up the idea of symbolic forms and focused on the conceptual meaning behind the equals sign. More broadly, we posit that the equals sign doesn't happen in isolation (the equals sign is the element of the mathematical sentences). Our analysis also helps us to see the role that equals sign is playing in the mathematical sentences.

Competing Terms cluster		**Terms are Amounts cluster**	
COMPETING TERMS	$\square \pm \square \pm \square \ldots$	PARTS-OF-A-WHOLE	$[\square + \square + \square \ldots]$
OPPOSITION	$\square - \square$	BASE ± CHANGE	$[\square \pm \Delta]$
BALANCING	$\square = \square$	WHOLE − PART	$[\square - \square]$
CANCELING	$0 = \square - \square$	SAME AMOUNT	$\square = \square$
Dependence cluster		**Coefficient cluster**	
DEPENDENCE	$[\ldots x \ldots]$	COEFFICIENT	$[x\square]$
NO DEPENDENCE	$[\ldots]$	SCALING	$[n\square]$
SOLE DEPENDENCE	$[\ldots x \ldots]$	**Other**	
Multiplication cluster		IDENTITY	$x = \ldots$
INTENSIVE·EXTENSIVE	$x \times y$	DYING AWAY	$[e^{-x\ldots}]$
EXTENSIVE·EXTENSIVE	$x \times y$		
Proportionality cluster			
PROP+	$\left[\frac{\ldots x \ldots}{\ldots}\right]$	RATIO	$\left[\frac{x}{y}\right]$
PROP−	$\left[\frac{\ldots}{\ldots x \ldots}\right]$	CANCELING(B)	$\left[\frac{\ldots x \ldots}{\ldots x \ldots}\right]$

Figure 1.1: *Symbolic forms identified by Sherin*[4;5]

Physics instructors want students to think critically about mathematics and the underlying fundamental concepts, rather than simply memorizing a series of equations and answers.

The ability to use mathematical tools to prove, solve, and argue physics concepts would provide students with an orientation in problem situations and this could thus improve students' problem-solving abilities. To address this, I use Sherin's symbolic forms[4;5] to investigate the conceptual and cultural meanings of the equals sign across physics contexts in Chapter 3.

Sherin believes that understanding a physics equation means students learn to understand it in terms of a vocabulary of elements called symbolic forms enabling the students to focus on the conceptual aspects of physics. Kuo *et al.*[76;77] confirmed the power of symbolic forms when students solve physical problems, arguing that these symbolic forms are plausible targets for instruction in introductory physics. Arons[88] stated that a lack of mathematical skills may prevent the understanding of physics concepts.

Sherin[4;5] proposed the symbolic form as a cognitive mathematical primitive that associates physics conceptual meaning with mathematical symbols. He believes patterns that students use came from their previous mathematical knowledge. His finding was supporting p-prims[2], which come to serve as heuristic sign for formal knowledge as expertise develops. He described a list of specific symbolic forms and representational devices that employed by the students in solving physics equations. He discussed that using symbolic forms provided a different interpretation of students understanding.

Sherin described the relationship of symbolic forms to conceptual knowledge: "Each symbolic form associates a simple conceptual schema with an arrangement of symbols in an equation. Because they possess these symbolic forms, students can take a conceptual understanding of some physics situation and express that understanding in an equation. Furthermore, they can look at an equation and understand it as a particular description of a physical system (p. 482)".

These forms are context-dependent, and equivalent mathematical equations can have different symbolic forms. For example, the right hand side of the kinematic equation $v_f = v_0 + at$ can be interpreted as a symbolic template "base+change", with the initial velocity v_0 modified by the change in velocity brought about by acceleration. Another example is the topologically equivalent equation for net force of a spring-gravity system $F_{net} = -kx - mg$. However, it is more likely to be interpreted as a "sum of parts", with F_{net} is the sum of the various forces, in this case gravity mg and spring kx.

Additionally, Tuminaro and Redish et al. *et al.*[81] used symbolic forms to model how students translate mathematical solutions into physical understanding. Kuo[76] *et al.* found that students do not expect conceptual knowledge of mathematics to connect to their problem-solving.

In Chapter 3, first I present an analysis of the different physical meanings associated with the equals sign that can be inferred from introductory and upper-level physics textbooks. Then, I discuss how physics students use the equals sign in an electrostatics course written homework and compare their solution to the textbook solutions manual. In doing so, we are able to look for patterns and compare the ways students solve problems to the solutions manual which was written by an expert (physicist).

1.2.3 Epistemological framing

A type of resource that is particularly important in Chapter 4 is an epistemic resource. Hammer[3] describes epistemic resources similar to conceptual resources.

I use the theoretical lens of epistemological framing to analyze students' group frame while they are solving physics problems. Based on Scherr and Hammer[7], a student's epistemological frame addresses information about how they view the nature of knowledge within the context. Framing supports students' problem-solving as they decide what knowledge to employ and the necessary steps to solve the problem. Previous work on framing at the upper-division level has investigated how students coordinate mathematics and physics ideas and how students frame their problem-solving as expansive or narrow[89].

Dewey *et al.*[90] (1929) initiated the conversation of reflection in his work which translates into "how we think" in a specific situation. He characterizes different modes of thinking by asserting reflection or reflective thinking in problem-solving. This involves framing and re-framing the problem. Epistemological resources are activated by reflective thinking around any set of unsettled controversial topics[43]. Epistemological resources usually appear as a network of activated resources that may look like a stable belief, and they can play different roles in different frames.

The concept of framing is borrowed from Goffman's Frame Analysis[91]. He studied people's expectations about their activities and found how these expectations influence their behavior to answers the question of "What is it that's going on here?[91–94]. Students use framing to make sense of the activities that they are engaged in, including problem-solving[7;9;95–97]. Frames are connected to students' learning outcomes in traditional classrooms[98]. Hammer *et al.*[95;99] provide a framework for student learning in physics by which students recruit conceptual and epistemological resources, including framing. Students have an epistemological beliefs that can influence the results of their learning. In problem-solving, students take cues from the problem statement[35], their group mates[100], and the instructor[89] for how to initially frame a problem or how to change frames when they get stuck.

Epistemological frames are context dependent[99]. We can look at clusters of behaviors[100] in order to infer those frames[100]. For example, students in a *lecture* frame might sit quietly, facing forward, and write in their notebooks. In contrast, students in a *joking* frame might laugh, look at each other (instead of their work), and/or operate lab equipment in non-standard ways; their discourse could focus on non-physics topics, or present physics topics in a humorous manner. Prior work on framing in physics has focused strongly on this kind of frame-activity match.

In 2009 Scherr and Hammer described an analysis of the major behavioral clusters in students' discourse during an in-class activity which corresponded to students epistemic framing[7]. They found that the groups coordinated their behaviors by switching back and forth between several behavioral clusters. Their analysis of students' framing during collaborative problem-solving revealed four epistemological frames: worksheet, joking, TA, and discussion.

Based on the categorization of Bing and Redish[9] students' epistemological framing could separate into four frames for usage of mathematics in physics. They analyzed students' understanding while the students translated physical ideas into mathematical forms. These studies are an excellent entry point into how groups of students frame discussion in physics. Analysis of the students' discourse show different ways that the groups are framing their activity.

The Bing and Redish framework[101] also cannot be used to analyze the student and instructor equally. In my work, I first characterize the markers of each frame, focusing on analyzing students' groups frame. Then, I present a pair of examples that show how often students transition between these frames.

In Chapter 4, I provide evidence of how groups of students frame discussion in a physics classroom while solving a problem. I use videos of students solving physics problems in an upper-division E&M classroom. I consider two epistemic frames which are common in students' discussions during problem-solving in group: sense-making and answer-making. I first characterize the markers of each frame, focusing on analyzing students' group frame. We also present a pair of examples that show how often students transition between these frames in order to solve physics problems productively.

Chapter 2

Student understanding of electric and magnetic fields in materials[1]

2.1 Introduction

Learning to think scientifically is extremely important for all students. All science, technology, engineering, and math (STEM) majors must take physics; thus, research into how students learn physics is important for all STEM students. Solving physics problems and learning physics at the upper-division level is a complex endeavor, and each student is unique in the way they process information to solve physics problems and understand physical concepts.

2.2 Theoretical framework

Previous research on Resource Theory and Mental Models in Electricity and Magnetism guides the research described in this Chapter. In Chapter 1, I gave an overview of a resource-based framework and their characteristic of resources[3;103]. In this Chapter, I use resource theory from the family of the knowledge in pieces (KiP)[1–6] theories to describe how students

[1]This analysis was published in the American Journal of Physics[102]

solve problems in an upper-division electricity and magnetism course.

DiSessa's phenomenological primitives or "p-prims," for short, has been considered as a simplest, most atomic pieces of students intuitive knowledge in physics[1] that derived from experiences. In order to investigate student understanding in physics, diSessa interviewed 20 introductory level physics students. DiSessa describes that p-prims are not context specific; rather they provide the general rule to describe various contexts. A p-prim is neither right or wrong, but can be associated with an event correctly or incorrectly. One example, "closer is stronger" is a p-prim that is correct if you consider the closer your hand is to a fire, the hotter you feel. However, it would be incorrect if we think about the seasons misconceptions (Why is it warmer in the summer than the winter?).

Hammer[3] used the term "resources" to describe conceptual models that students bring in to physics classrooms. Resources are small ideas that explain a concept of a specific topic. However, they are larger than the p-prim. From the resource-based framework perspective students have ideas that can activated in different situations such as solving physics problems. In this sense, they use these activated resources to construct their knowledge. It is important to note that resources themselves are not inherently right or wrong. Rather, the activation of resources is context-dependent. Students use resources by activating and linking them to form more complex mental models.

2.3 Context

The data analyzed for this study comes from students' written test responses spanning two years at Kansas State University. The upper-division E&M course is available every fall semester, and typically covers the first half of Griffiths' textbook[104], Maxwell's equations in matter and vacuum. The class meets four days a week for fifty minutes at a time. About one third of the days are tutorial days in which students complete guided practice problems in small groups instead of listening to a lecture.

There were two cohorts of students who took the class in 2014 and 2015. In 2014, on the final exam ("Final 2014"), 19 students were asked both parts (1) and (2) from Fig 2.1. In

2015, 18 students were asked only part (2) of this problem *(electric fields)* near the beginning of instruction on this topic in the 12^{th} week of the semester ("Mid-Semester 2015", we treated this as a pre-test), and all parts of the problem on their final exam ("Final 2015"). Between the 2015 pretest and final, students were given targeted instruction on this problem. Thirty-seven students in total completed the class in 2014 and 2015, and 55 assessments (written test responses) were collected, both during instruction and at the final exam. We analyzed all usable answers to find patterns and trends in the students' use of resources, and we also searched for patterns among the 2015 students' responses during the semester and after they completed the class.

Linear materials encounter strong fields, and then linearity breaks down. *Hint: You don't have to do any quantum here! Our ordinary assumptions about matter are sufficient.*

1. In a sufficiently strong external magnetic field, a linear material cannot become more magnetized. That is, $\mathbf{M} = \chi_m \mathbf{H}$ holds until some threshold value of $\mathbf{H}$, above which $\mathbf{H}$ may increase but $\mathbf{M}$ cannot. Explain, in words and pictures as appropriate:
   (a) why this happens; and,
   (b) what happens in the material when the threshold value of $\mathbf{H}$ is exceeded.
2. In a sufficiently strong external electric field, a linear material cannot become more polarized. That is, $\mathbf{P} = \epsilon_0 \chi_e \mathbf{E}$ holds until some threshold value of $\mathbf{E}$, above which $\mathbf{E}$ may increase but $\mathbf{P}$ cannot. Explain, in words and pictures as appropriate:
   (a) why this happens; and,
   (b) what happens in the material when the threshold value of $\mathbf{E}$ is exceeded.
3. (bonus) Comment on how these two situations are analogous and disanalogous to each other.

Figure 2.1: *Final exam question for 2014 and 2015 cohorts.*

2.4 Data analysis

We reviewed all 55 student exams, seeking patterns in student understanding. Three students did not answer the question and two students wrote about the unrelated phenomenon of polarization of light. We discarded these students' exams from further analysis. In addition, one student did not take Final 2015 and one student was absent for Mid-Semester 2015, leaving 50 usable responses in all, 33 for 2015 and 17 for 2014.

To find patterns, we considered each response's resources, drawing resource graphs[37] to generalize them across responses. We use resource graphs to link resources activated in particular contexts. As themes emerged in the data, we sought a categorization scheme which would both capture the rich variety of student responses and make meaningful categorical differences among them. We iteratively developed an emergent coding scheme linking specific student language to specific resource use.

We classified each response as *sub-atomic* or *super-atomic*, which are explained in the section 2.5 and appendix A. Then we noted which resources each student used by the criteria in our code book. If the student's resources did not fall into any of the categories we defined, we marked them as "other".

When our coding scheme was stable, we invited an additional researcher to separately code student responses. He categorized 20 randomly selected answers, using our categorization scheme and our code book for evaluation during inter-rater reliability testing (IRR). Before the discussion, 82 % of his identified resources and ours overlapped. After discussion, which included clarifying and improving parts of the code book and discussing each response categorized differently, we repeated this procedure with 20 different responses and found 100 % agreement.

2.5 The problem and its solution

The following is a complete and correct response to the exam question students were asked. When a dielectric material is placed in an electric field, its atoms become polarized. This means that the negative electron cloud around the positive nucleus is slightly displaced from the center. This displacement of charges within the atoms forms electric dipoles with separation linearly proportional to the strength of the electric field, as given by the equation $P = \epsilon_0 \chi_e E$ where P is net polarization, E is the electric field, χ_e is a property of the material (susceptibility), and ϵ_0 is constant. When the electric field's strength exceeds a certain threshold value, electrons become separated from their nuclei, converting the dielectric into a conductor. This is called dielectric breakdown.

When a linear paramagnetic material is placed in a magnetic field, whatever magnetic dipoles that already exist become more aligned with the field, tending to point in the same direction as each other. As opposed to polarization, magnetization of a material does not separate any charges, but merely changes the random direction of spins within the atoms to be more uniform. The magnetization M of a material is given by $M = \chi_m H$ where H is the magnetic field and χ_m is a constant dependent on the material. The linear relationship between M and H breaks down after H is strong enough to align all of the magnetic moments of the atoms parallel to it. After that threshold, H can increase but M cannot. No breakdown of the material occurs.

2.6 Results

2.6.1 E-Field

As part of our investigation, we looked at how students considered what happens to a dielectric material in an extremely strong electric field. We examined their responses for evidence of resources being activated. When observing the students' answers to the polarization question, we found that the resources students activated generally fell into two groups.

The first group, which we call *sub-atomic*, consists of students who used resources related to the internal structure of the atoms within the material. This includes mention of electron clouds along with nuclei, stretching of the negative and positive charges within the atom, drawings of dipoles with positive and negative sides, and internal forces of the atom versus the external force of the electric field. 23 of 50 responses are in this category.

The second group, *super-atomic*, consists of students who, instead of thinking about the internal structure of the atom, talked only about the material in general. These students often considered the problem in terms of the model of positive and negative charges moving throughout the material and collecting on one side, as opposed to thinking about the atoms themselves becoming dipoles aligned with, and pulled apart by, the field. Included in this category are drawings of material with pluses and minuses lined up within it (that do not form polarized atoms), mention of electrons or charges without reference to an atom, and mention of the word "dipole" without description or depiction of its structure. 27 of 50 responses are in this category.

When comparing the answers of the *sub-atomic* and *super-atomic* groups represented in Table 2.1, we found that if a student considers the internal structure of the atom during polarization, they are very likely to arrive at the correct answer, dielectric *breakdown*. This is true for all three testing situations we evaluated. Furthermore, on the two tests where students had not been given the question before (Mid-Semester 2015 and Final 2014), the students that took the *super-atomic* route were not likely to get to *breakdown* over other answers. This is especially true for Mid-Semester 2015, when the students had not yet been taught the material.

	Sub-atomic	**Super-atomic**
Final 2014		
Break down	5	3
Saturation	1	6
Others	0	2
Mid-Semester 2015		
Break down	7	1
Saturation	0	7
Others	0	1
Final 2015		
Break down	9	4
Saturation	1	2
Others	0	1

Table 2.1: *Resource groups activated by students versus their answers while writing about material in fields.*

There were other variations of resources used within the large groups of *sub-atomic* and *super-atomic* resources. Students who used *sub-atomic* resources and reached *breakdown* tended to justify their answers one of two ways. In the first approach, students described the internal atomic forces holding the electrons and nuclei together, and how an electric field above a certain threshold would provide a large enough force to overcome the internal force and break electrons away from their atoms. We called this resource *balancing forces*, and cluster **A** is the name we gave the cluster of resources including *sub-atomic* resources, *balancing forces*, and *breakdown*. In the second method, students described how maximum polarization pulls the electron cloud so far away from the nucleus that electrons break from their nuclei. We called this resource *maximum displacement*, and cluster **B** is the name we gave the cluster of resources including *sub-atomic* resources, *maximum displacement*, and *breakdown*. They are essentially the same phenomenon, but *balancing forces* is a more rigorous description. Fig 2.2 depicts the common clusters of resources used by students. The diagram on the left represents clusters **A** and **B**, and the diagram on the right represents cluster **C**.

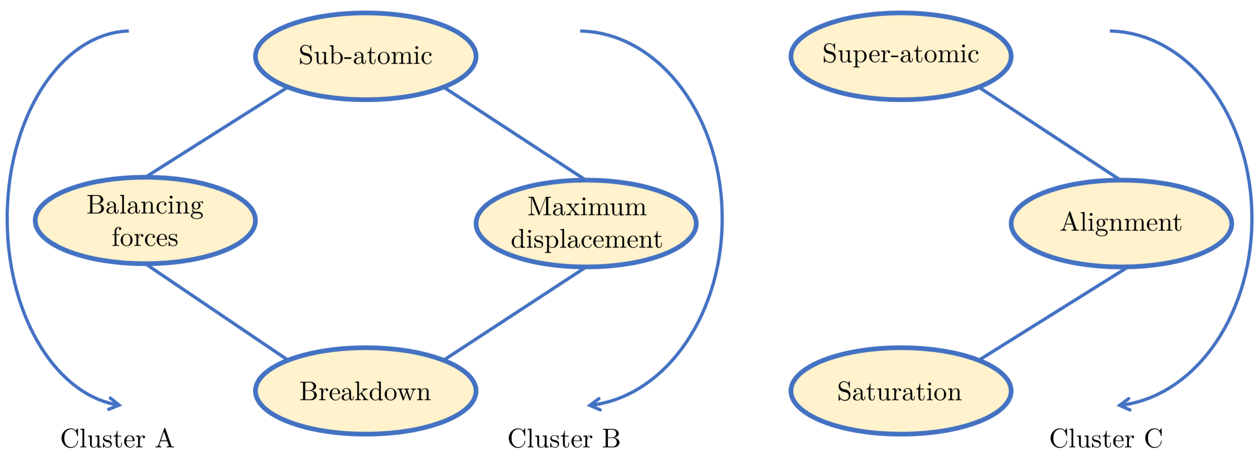


Figure 2.2: *Resource graph for materials in electric fields.*

An example of a student response that includes *sub-atomic* resources and the *balancing forces* resource (cluster **A**) is that of "Kate"[2] in Mid-Semester 2015. "Polarizing atoms means slightly offsetting the negative electron cloud from the positive nucleus". It is clear that Kate uses *sub-atomic* resources to frame the question. She goes on to say, "If the field doing this is strong enough, it will separate the two entirely, since it will overcome the Coulombic force attracting the electrons to the nucleus. The electrons will gather on one

[2] All student names are pseudonyms.

side of the material". The use of the words "overcome" and "force attracting the electrons to the nucleus" shows that *balancing forces* activated along with *breakdown*.

In her answer for Final 2015, Kate used cluster **B** instead. She wrote, "The external electric field pulls on the electron clouds in the individual atoms/molecules, creating a polarization". She mentioned electron clouds in relation to their atoms, so we classified her as using *sub-atomic* resources, seeing as she conceptualized the situation on a *sub-atomic* level. Kate continued, writing "As the field increases, the electron clouds get pulled farther and farther away from the nucleus, until they can go no farther without leaving the nucleus entirely". We classified this resource as *maximum displacement* because she mentioned the distance between the electron clouds and the nuclei reaching a breaking point. For part two of the question, she wrote, "the electrons are ripped away from the nuclei, causing a brief flow of charge (dielectric breakdown)".

Students who did not think about polarization at the *sub-atomic* level tended to justify their answers using a description of the dipoles or charges aligning with the field until none of the dipoles or charges could be more aligned. This resource, *alignment*, was usually paired with the final answer of *saturation*. These students wrote that nothing significant happened to the material besides *alignment*, failing to mention *breakdown*. We called this cluster of resources cluster **C** which included *super-atomic* resources, *alignment*, and *saturation*. Several students' responses (fifteen responses in all) that used this cluster made no mention of separation of charges during polarization and only mentioned *alignment* of the dipoles, treating polarization and magnetization as the same phenomenon in their answers. Many students used a model of charges aligning in some way across the material while separating as well.

An example of cluster **C** is Alex's answer in Final 2014. He wrote, "polarization occurs when an E-field pushes all + charges one way and the − charges move the opposite direction. This causes an E-field from the difference between separated + and − charges". There is no mention of atoms here, and the term "charges", especially when he discusses positive charges, indicates his use of the model of charges moving throughout an insulator and causing net effects rather than electrons moving within an atom. He went on to write, "eventually all the

$+$ will be as far to one side as possible and all of $-$ will be as far as possible in the opposite direction. The charges are as far away as possible with all the charges segregated. At this point, no more charges can move so E will increase, but P can't...". Here, he activates the resources *alignment* and *saturation*. In summary, he uses *super-atomic* resources, *alignment*, and *saturation*.

The rest of the students' answers indicated the activation of other resource clusters which we grouped into the miscellaneous cluster **D**. This includes any answers that were neither *breakdown* nor *saturation*. It also includes students who used *sub-atomic* resources but reached an answer of *saturation*, or students who used *super-atomic* resources but reached an answer of *breakdown*. And finally, it includes the few students who used none of these or misunderstood what the question asked of them.

The grouping of these resources into clusters aided us in finding patterns in student responses over varied context and amount of instruction. As stated before, for all three testing situations, using *sub-atomic* resources almost always coincided with activating the resource of *breakdown*. Conversely, activation of *super-atomic* resources typically coincided with activation of the *saturation* resource instead of *breakdown*. Researchers have taken advantage of this novelty to gain an understanding of children's knowledge of the relations between addition and subtraction by utilizing children's use of conceptually-based shortcuts as an indicator of conceptual understanding because understanding the inverse or associative relations between addition and subtraction is required to implement the inversion and associativity shortcuts. *Sub-atomic* and *super-atomic* students, who arrived at *breakdown*. In fact, 13 out of 17 students reached *breakdown* on Final 2015, whereas only 8 out of 16 reached *breakdown* on Mid-Semester 2015. Below are details about why this may have occurred.

Table 2.2 summarizes the number of students who used each cluster on Mid-Semester 2015 and Final 2015. Four students switched from using cluster **A**, **B**, or **C** in the pretest to using cluster **D** (and still getting *breakdown*) on the final. Take Zachary's response for Final 2015 for which he wrote, "The material is bounded. Above and below the faces of the material are regions of different ϵ_r and χ_e. These regions do not have the same property as the linear material, and so the max P occurs at E threshold, when all the charges are on opposing faces". Along with his written answer, Zachary also drew a diagram of a rectangular prism in an electric field. He went on to say, "to remain in equilibrium, the dipole $E_i = E_{ext}$. This is achieved by highly polarizing the material, so all the positive charges are on top face, and $-$ charges on bottom face. This occurs at E threshold. If $E_{ext} > E_{threshold}$, the charges can't balance out, and the charges begin to strip away from the material and end the linear property".

Zachary was able to reach *breakdown* without activating *sub-atomic* resources, unlike in his answer for the question during the pretest for which he used cluster **A**. He discusses only *super-atomic* qualities and phenomena in his response after instruction about materials in electric fields and the internal process of polarization. This could be due to the fact that the instructor facilitated activation of those *sub-atomic* resources in a way that allowed them to go from being plastic to solid in Zachary's mind. The instructor reviewed the exact question after the pretest, and used *sub-atomic* descriptions in a Mid-Semester lecture including the fact that each atom is made up of a little bit of negative and positive, and the positive center is surrounded by the negative outside. She also describes *breakdown* as when "electrons get ripped away from atoms", and contrasts separation and alignment. This lecturing could have increased Zachary's ability to use *breakdown* as a resource on the final exam without accessing its internal structure or having to justify it further by using *sub-atomic* resources.

Type of clusters	Mid-Semester test	Final test
Cluster A	4	7
Cluster B	3	2
Cluster C	7	2
Cluster D	2	6

Table 2.2: *Comparing the cluster of resources during Mid-Semester and Final 2015*

Four other students used cluster **C** or **D**, getting *saturation*, on the pretest, and then switched to cluster **A** or **B** on the final, indicating that they understood the lecture and used the resources given to them by instruction to correctly answer the final. (Note that when we use the word "correctly" here, we are referring only to the final answer and are not commenting on the correctness of the reasoning the student used.) The remaining students either used the same cluster for both exams, or used a different cluster resulting in the same answer for both.

2.6.2 B-field

The second part of our research was to analyze data from the portion of the question on the two final exams about materials in extremely high magnetic fields. This part of the question was not included in Mid-Semester 2015. Unlike the polarization question, none of the students who answered the magnetization question had seen the problem before their final exam. However, they had all been taught concepts about magnetic fields and magnetization through practice problems and lectures prior to the final. The purpose of this question was to get students to compare and contrast what happens to linear materials when they are highly polarized versus highly magnetized.

The vast majority of student responses included only *super-atomic* resources to describe and explain magnetization and its effect on the material. These resources consisted mainly of *alignment* of atoms in some sense. Only two students did not reach the correct answer of *saturation*, and interestingly, those students used *sub-atomic* resources in their responses. Those students mentioned the internal structure of the atom during magnetization, and they concluded with *breakdown* of the material.

Breakdown and *saturation* are the correct answers for E-field and B-field, respectively. So, by switching the context, the same resource can be applied correctly or incorrectly. That is, resources by themselves are neither right nor wrong.

2.6.3 Comparison between class activities and student responses

We recorded the class meetings in 2015 about magnetization as part of a broader project on student reasoning during class. Upon reviewing the lectures, we discovered how different the magnetization lectures were from the polarization lectures discussed in the last section. The instructor used almost no conceptual or *sub-atomic* description of magnetization, and instead focused on bolstering the students' mathematical understanding of the way material behaves in high magnetic fields. She mentioned ways different materials hold magnetization and for how long (such as the ferromagnet's ability to become a permanent magnet), and several students included that information in their responses. However, the only conceptual explanation on a *sub-atomic* level was that atoms can align with or against the field based on the thing that is doing the spinning to make the current in the dipole. Instructor says that this "thing" is "all kinds of quantum-y things" and has to do with how electrons are paired in atoms.

This is a contrast from the lecture on polarization which focused on a *sub-atomic* description of *breakdown*. The student responses reflect this difference. Although only two students said that something happens to the material besides maximum alignment (and therefore *saturation*), the "things" that students said were aligning varied widely. Over twenty different words were used for this "thing", and most of the pictures drawn were arrows lining up with each other, indicating a *super-atomic* model of magnetization. The words used included correct terminology such as "magnetic moment", "dipole", "electron spin", and incorrect or incomplete terminology such as "electrons", "atoms", and "little pieces". All answers including *alignment* and *saturation* were given credit. This lack of a complete group of resources to make up a mental model of magnetization could be due to the instruction the students were given. The students lacked a link between the idea that material is made of atoms and that something about those atoms aligns during magnetization. A similar result was found in Borges and Gilbert's research in which they describe student use of a "causal agent" (in this case, the "thing" that is aligning) to fill in logical gaps left by the question.[45] Furthermore, previous work on how students understand electric and magnetic fields together suggest that students often confuse these fields or their effects with each other[105–107]. For example, Scaife and Heckler found that interference between electric and magnetic concepts can make students confused. They also stated that students' responses depend on whether electric or magnetic force questions are posed first, and this effect depends on whether electric or magnetic force was most recently taught[107].

The wording of the question may have also played a role in the high number of *saturation* responses. Although both questions about the electric and magnetic fields are worded the same, the data should not be analyzed independently from the questions asked. This is because the nature of the response expected of the student for each question was different, and the question itself can activate certain resources. The phrase "cannot become more magnetized" in the question is essentially the definition of saturation, and this may have activated resources related to *saturation*. The students could have then activated resources to link their knowledge of magnetization with the idea of *saturation*. In conclusion, wording of this part of the problem may aid students to find the correct answer, *saturation*, and help them to obtain full credit.

Similarly, the polarization question uses the phrase "cannot become more polarized". This phrase may have activated *saturation* resources in some of the students as well. However, for the polarization part, the instructor expected students to take their mental models of materials in electric fields and extrapolate them to explain a special case, breakdown. They are expected to reason further than the default of *saturation* set by the question. In other words, although the wording of the question was identical for both magnetization and polarization, it favored *saturation* as opposed to *breakdown*. Borges and Gilbert's research also supports the claim that student responses and explanations should not be analyzed separately from the question they were asked[45].

Though the wording is analogous for both questions, in the magnetization case it cues students to think appropriately, but in the polarization case it cues them to think inappropriately. This interaction effect between question phrasing and students' resource use is important to note when designing questions and analyzing students' responses.

2.7 Conclusion

I discussed the clusters of resources that were activated together when upper-division E&M students expounded on the behavior of materials in fields. Some examples show that those clusters can change with time and context, specifically with increased instruction of the concepts in question. I have offered insight to which mental models are most helpful for fostering complete conceptual understanding of polarization and magnetization.

The data indicate that use of resources related to the internal structure of the atom during polarization increased likelihood of activating *breakdown*. Students who did not activate these *sub-atomic* resources tended to activate *saturation* instead. This predictive relationship was not as strong on Final 2015, where we argue that because the students had seen the question and received instruction, the resource clusters they used changed from Mid-Semester 2015. The *breakdown* resource became more solid and required less justification for use, making the students' answers less *sub-atomic* but not less correct.

I also assert that wording of a question has a role in activating certain resources in the student and can induce students to think mechanistically[108]. By reading the question, students knew that some aspect of a material becomes saturated when it is in an extreme magnetic field, and they filled in objects to link their knowledge that material is made up of "things", and that these things align in the presence of the field.

In conclusion, the goals of this study were to identify the clusters of resources that successful students activated while answering an upper-level conceptual problem in E&M, and to highlight the role of the instructor to facilitate activation of those resources. These results should improve our understanding of how students reason about fields in materials and could yield insight into instructional strategies to improve the learning and teaching of physics at upper-division level.

It is important to note that it is possible to have a complete mental model that is applied incorrectly. For example, some participants in our study showed evidence of having a complete mental model of polarization of light that they applied incorrectly to our question about polarization of materials. It is also possible to have an incomplete mental model that is applied correctly. For example, a student could make correct predictions about the results of a physical situation, but may be only able to do so for very specific cases.

2.8 Summary

In this chapter, I discussed the clusters of resources that emerge when upper-division students write about electromagnetic fields in linear materials. The data analyzed for this paper comes from students' written tests in an upper-division electricity and magnetism course. I examined how these clusters change with time and context. The evidence shows that students benefit from activating resources related to the internal structure of the atom when thinking about electric fields and their effect on materials. I argued that facilitating activation of certain resources by the instructor in the classroom can affect the plasticity of those resources in the student, making them more solid and easily activated. In addition, I found that the wording of the questions posed to students affects which resources are activated, and that students often fill in resources to link known phenomena to phenomena described by the question when lacking detailed mental models.

Chapter 3

Encapsulating meaning: The equal signs in undergraduate physics education

3.1 Introduction

In recent years, the interest in mathematics as the language of physics has been growing steadily. Taking up this metaphor, in this Chapter we examine "grammar" on a minute level to investigate the particular dialect of mathematics (principally equal signs) spoken in physics textbooks and students' physics homework.

The question is, "what does the equal signs mean?" The concept of equality is surprisingly complex. Several studies have documented that students often misinterpret the equal signs as an operational symbol rather than a relational symbol [58;109–113]. Understanding the equal signs in a relational manner is important due to its role in upper-level mathematics and physics courses.

3.2 Theoretical framework

The research project presented in this Chapter has two phases. In phase one, we explore the conceptual meaning behind mathematical formalisms. The focus of this part is narrowed specifically to the equal signs in the context of physics equations.

The role of the textbook varies from classroom to classroom and between different instructors, but we all still agree that textbooks play a vital role in achieving the objectives of the curriculum. Textbooks are the main source for lots of instructors. The way textbooks are designed and structured can provide a basic framework for them on how lessons can be taught. Physics textbooks are designed to give cohesive language to the physics context by providing mathematical explanations and examples. Because textbooks are important source of teaching and learning, we have presented an analysis of the use of equal signss in five physics textbooks, in order to investigate the language that authors - as an expert physicist - used in physics context.

In doing so, we do not ask how the "=" understanding might be used to solve a problem, but rather whether thematic categories arise that are plausible to a physicist's interpretation of the symbol. Focusing attention on the structure of the equations involving the equal signs leads to an understanding of an equation's underlying meaning which can help illuminate the dialect of mathematics used in physics.

Writing in the Knowledge in Pieces (KiP) tradition[1–3], Sherin's symbolic forms framework[4;5] links mathematical equations to intuitive conceptual ideas. This framework explains how students create, describe and evaluate equations to understand physics concepts and provides a small grain size for analysis into the grammar of students' mathematics use in physics. We take up the idea of symbolic forms[4;5] and focus on just one aspect: the conceptual meanings behind the central symbol in every equation, the equal signs. Specifically, we investigate the different conceptual meanings of the equal signs within each equation sentence that emerges in physics problem-solving and how these meanings shift in relative frequency across contexts and speakers.

Our method parallels that of Burton *et al.*[114], who studied published journal articles in a variety of mathematical sub-fields to identify a "natural language" in their epistemological practice. We find a shared focus in the work of Kress[115] (in Cope and Kalantzis book) in striving to understand "what language (including, in our case, math symbols) is doing and being made to do by people in specific situations in order to make particular meanings" and agree with Burton *et al.*[114] that doing so may "shed some light on the values and meanings of the practices" of physicists in the pedagogical context.

Then, in the phase two of the project, we examine how upper-division undergraduate students use these mathematical sentences in their electromagnetic fields homework, and compare the students' "dialect" to the one presented in the solution manual for the course textbook.

3.3 Phase one: How Physics Textbooks Embed Meaning in the equal signs[1]

3.3.1 Data selection: Textbooks

Our study focuses on five physics textbooks (Table 3.1) spanning introductory through senior-level coursework in *Mechanics*, *Electrostatics*, and *Quantum Mechanics*. Physics curricula are often cyclical, and later courses often return to previously covered material in more depth and mathematical sophistication. Because of this, we selected Chapters with similar content, allowing us to see differences across both content area and level.

At the introductory level, we study *University Physics with Modern Physics* (14^{th} edition)[117], a popular introductory physics textbook used in universities around the world. Chapters 21 and 22 of this text focus on student understanding of specific topics such as electric charge, electric field, and Gauss' law.

At the middle division, we study *Modern Physics*[118] and *Classical Mechanics*[119]. Modern Physics balances the concepts of modern physics with their historical development as well as the experimental evidence supporting theory. Chapter 5 of this text includes the wave

[1]This analysis was submitted to the Journal of Physical Review Physics Education Research[116]

behavior of particles, the time-independent Schrödinger equation, the "particle in a box" problem in one-dimension and two-dimensions, and the quantum harmonic oscillator. The chapter also includes the solution to the Schrödinger equation for a one-dimensional simple harmonic oscillator and discusses why the simple harmonic oscillator is an important system in quantum mechanics.

Classical Mechanics [119], covers Newton's laws of motion, projectiles and charged particles, momentum and angular momentum, energy, oscillations, and Lagrange's equations. Chapter 4 of this text covers conservation of energy, central forces systems, energy of a multi-particle system, and elastic collisions.

At the upper-division, we study *Introduction to Electrodynamics* [104] and *Introduction to Quantum Mechanics* [120]. These are the two most popular textbooks for their respective courses. Introduction to Electrodynamics presents a strongly theoretical treatment of electricity and magnetism. Chapter 2 focuses on electrostatics and electric fields, particularly Coulomb's Law and Gauss' Law. *Introduction to Quantum Mechanics* balances discussions of quantum theory with mathematical treatments from a wave functions-first perspective. Chapter 2 covers solving the time-independent Schrödinger equation for both the particle in a box and the harmonic oscillator.

Physics undergraduate textbooks in general are extremely consistent in content and presentation, suggesting that our results should be generalizable to other physics textbooks.

3.3.2 Methodology

The categorization scheme was developed through iterative readings of the textbooks. After reading each chapter, another researcher and I individually wrote down the key points they noticed about the equations. After three chapters, I created sets of notes that described each equation in symbolic template and conceptual meaning associated with the equality symbol. The first draft of categories came from this data. Then, we actively engage with equations, we began the data analysis process by reading and carefully re-reading each selected chapter to identify the category of each equality symbol. After, coded all equations

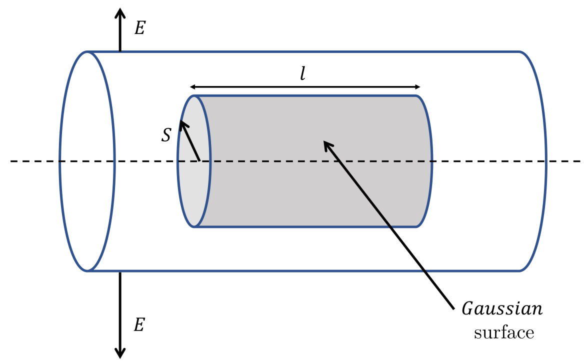
Textbook level	Textbooks	Chapters	Description
Introductory	University Physics with Modern Physics, 14^{th} ed. Young & Freedman	21, 22	Chapter 21 and 22 focus on how objects become electrically charged, how we can determine the amount of charge within a closed surface, and how to use Gauss's law to calculate the electric field.
Intermediate	Modern Physics, 2^{nd} ed. Kenneth S. Krane	5	Chapter 5 focuses on the time-independent Schrödinger equation, the particle in a box problem in one dimension and two dimensions, and the quantum harmonic oscillator.
	Classical Mechanics, 2005, John R. Taylor	4	Chapter 4 focuses on central-force problems, mechanics in non-inertial frames, coupled oscillators and nonlinear mechanics.
Upper-division	Introduction to Electrodynamics, 4^{th} ed. David J. Griffiths	2	Chapter 2 covers vector analysis, electrostatics, potentials, magnetostatics, electric and magnetic fields in matter, electrodynamics, particularly Coulomb's Law and Gauss' Law.
	Introduction to Quantum Mechanics, 2^{nd} ed. David J. Griffiths	2	Chapter 2 covers wave functions, the time-independent Schrödinger equation, and quantum mechanics in three dimensions, particularly the particle in a box and the harmonic oscillator.

Table 3.1: *Textbook selection.*

individually, we presented our results to the group to refine the articulations of the categories. We compared our coding together and discussed about our similarities and differences. We clustered together all equations that have similar meanings and wrote robust descriptions of each of category. After several more iterative cycles of analysis and refinement, once we have a code book and the coding scheme was judged stable, the outside researcher used the coding scheme on random sections from each chapter in order to establish inter rater reliability testing (IRR). 87.5 % of initial coding overlapped with the original researchers. After clarifying discussions, including tutorial about the code book and discussing about each equation, subsequent IRR tests resulted in 100 % agreement.

An example of the coding applied to a problem in the textbook is shown in Fig 3.1. Figure 3.1 shows a problem as stated in the textbook with a worked solution, including both equations and descriptive text. Every equal sign is assigned a code indicating its categorization ($\overset{\mathrm{D}}{=}$ for *Definitional*, $\overset{\mathrm{C}}{=}$ for *Causality*, $\overset{\mathrm{A}}{=}$ for *Assignment*, $\overset{\mathrm{B}}{=}$ for *Balancing*, or $\overset{\mathrm{M}}{=}$ for *Calculate*). We reiterate that, in this study, every equal sign that appears in the selected chapter is assigned a unique code.

Example 2.3
A long cylinder carries a charge density that is proportional to the distance from the axis: $\rho \overset{\text{A}}{=} ks$, for some constant k. Find the electric field inside this cylinder.



Solution: Draw a Gaussian cylinder of length l and radius s. For this surface, Gauss's law states:

$$\oint E.da \overset{\text{D}}{=} \frac{1}{\epsilon_0} Q_{enc},$$

The enclosed charge is

$$\begin{aligned} Q_{enc} &\overset{\text{D}}{=} \int(\rho d\tau) \overset{\text{A}}{=} \int(ks')(s'ds'd\Phi dz) \overset{\text{M}}{=} 2\pi kl \int_0^s s'2ds' \\ &\overset{\text{M}}{=} \tfrac{2}{3}\pi kls^3. \end{aligned}$$

Now, symmetry dictates that E must point radially outward, so for the curved portion of the Gaussian cylinder we have:

$$\int Eda \overset{\text{A}}{=} \int |E|\, da \overset{\text{M}}{=} |E| \int da \overset{\text{M}}{=} |E|\, 2\pi sl,$$

While the two ends contribute nothing (here E is perpendicular to da). Thus,

$$|E|\, 2\pi sl \overset{\text{A}}{=} \frac{1}{\epsilon_0}\frac{2}{3}\pi kls^3$$

Or finally,

$$E \overset{\text{M}}{=} \frac{1}{3\epsilon_0} ks^2 \hat{s}$$

Figure 3.1: *Visual depiction of coding of Example 2.3 from Introduction to Electrodynamics*

3.4 Categories

We examined physics textbooks from across the undergraduate curriculum to identify categories of equal signs use. A team of researchers including undergraduates, graduate students and physics faculty came to consensus on six categories of equal signs use and showed how the frequency of different categories varies by physics topic and course level.

Six categories emerged from our study: *Definitional*, *Causality*, *Assignment*, *Balancing*, *Calculate*, and *Hybrid*.

- **Definitional (D)**

As with most disciplines, physics uses careful definitions to constrain ideas to narrow and specific uses. The equal signs mediates this definition in mathematical expressions through an operational articulation "is never not". For example, the equation (here and henceforth we omit vector signs for simplicity) defines the inertial mass m -conceptually and operationally- as the ratio of net force to resulting acceleration.

$$m = \frac{F_{net}}{a} \tag{3.1}$$

The *definitional* equal signs, sometimes indicated with $\equiv$, establishes a fundamentally new quantity. The order in which an equation is read is important. Rittle-Johnson[121] has found that elementary-school children read all equations left-to-right, whereas physicists read in specific directions depending on their contextual use. *Definitional* type of equations read left-to-right: "Inertial mass is defined as the ratio of net force to acceleration."

- **Causality (C)**

Much of physics involves inferring causal relationships. Forces cause (operationally "lead to" or "result in") accelerations, and charged particles or currents cause electric or magnetic fields respectively. Examples of equations that indicate causal relationships include "forces cause accelerations" or "charges cause electric fields".

$$a = \frac{F_{net}}{m} \tag{3.2}$$

$$\oint \vec{E}.\vec{A} = \frac{Q_{enc}}{\epsilon_0} \tag{3.3}$$

The *causality* equal sign indicates a quantity, usually represented as a single variable *caused* by term(s) on the right-hand side. For example, equation 3.3 indicates the creation of an electric field $\vec{E}$ by existing charges.

We found that the majority of our disagreements in IRR were between two major categories: *causality* and *definitional* types of equal sign.

Sometimes, multiple type of codes was assigned to the data, depends on the other parts of the solution and context. We can build a mechanistic explanation[122] and attached it to the equation. For example, to describe the electric field, E, we can build a mechanistic story to that equation such as: The electric fields are created by electric charges. The charges exert a force on one another by means of disturbances that they generate in the space surrounding them. These disruptions are called electric fields. The electric field generated by a set of charges can be measured by putting a point charge q at a given position. From the electric field theory point of view, we say that the charge q creates an electric field E which exerts a force on a test charge. The electric field at the location of the point charge is defined as the force F divided by the charge q, $E = F/q$.

In *causality* type of equal sign, we can build a mechanistic story. This doesn't mean that we cannot build a mechanistic explanation for *definitional* types of equations, it means there is no need for such a description each time the equation is used[36]. We note that the causal agents are customarily placed on the right side of the equation and the resulting quantity on the left. In this way, causal equations differ from definitional equations in that they read more naturally right-to-left.

- **Assignment (A)**

Although, *definitional* and *causality* equations represent foundational physical relationships, it is sometimes necessary to temporarily associate concepts or variables. We label these temporary relations as *assignments* with an operational articulation of "let this equal that". In the simplest cases, this form assigns numerical values to quantities (e.g. $t = 4$) for use in solving problems or other manipulations. A more complex form is symbolic *assignment*. For example, this equation 3.4 encapsulates the idea that the net force on a mass hung from a spring is the sum of the gravitational and elastic forces.

$$F_{net} = kx - mg. \tag{3.4}$$

The net force is not always represented by this sum. Hence, this equation is not *definitional*, nor does the term $kx - mg$ cause a net force. Rather F_{net} and the sum $kx - mg$ may be used interchangeably for immediately subsequent calculations.

- **Balancing (B)**

Dynamic equilibrium is a physical concept in which two (or more) quantities are in balance, numerically equivalent, and often directionally oppositional[4]. When a mass hung from a spring reaches equilibrium and the net force is zero we write $kx = mg$, indicating that the force from the spring kx is equal and opposite to the gravitational force mg with the symbol template $\square = \square$.

The symbol template represents the structure of a mathematical expression without state the values or variables. Boxes demonstrate group of symbols (quantities or variables). Balancing can be independent of direction, however, as in the conservation equation 3.5 which represents the balance between the flux of a vector field and the time rate of change of an associated density field.

$$J = -\frac{\partial \rho}{\partial t} \tag{3.5}$$

Unlike the previous categories, *balancing* equations may be read in either direction, as the equation does not emphasize or elevate one quantity over another. The two are equal both numerically and in importance.

- **Calculate (M)**

The category identified is purely manipulative, indicating the result of a *calculate*. It can be thought of as equivalent to the use of a calculator button, a canonical example is $4 + 5 = 9$. The *calculate* equal signs appears primarily during problem-solving. This use of the equal signs only makes sense when read left-to-right.

- **Hybrid (H)**

Hybrid is a representation of *assignment* and *calculate* occurring simultaneously. This is generally seen when students find a shortcut in the problem-solving process. Familiarity in solving like problems allows the students to become comfortable in using shortcuts. Furthermore, mathematical skills improve conceptual reasoning about physical equations thus affording students to become more confident in utilizing shortcuts in the problem-solving process. For example, to find the net force the southern hemisphere in a uniformly charged sphere exerts on the northern hemisphere in terms of the radius, students write down the force in z direction

$$\begin{aligned} F_z &= \frac{3}{\epsilon_0}(\frac{Q}{4\pi R^3})^2 \int_0^R r^3 dr \int_0^{\pi/2} cos\theta sin\theta \; d\theta \int_0^{2\pi} d\phi \\ &= \frac{3}{\epsilon_0}(\frac{Q}{4\pi R^3})^2 (\frac{R^4}{4})(\frac{sin^2\theta}{2}\Big|_0^{\pi/2})(2\pi) \end{aligned} \tag{3.6}$$

Students assign a variable and solve the problem by calculating some parts in their mind and combine them for the solution. Table 3.2 summarizes the six categories, including operational articulation, canonical form and direction.

Category	Articulation	Direction
Definitional	"Is defined as..."	Left-to-right
Causality	"Leads to"	Right-to-left
Assignment	"Let this = that"	Left-to-right
Balancing	"This is balanced by..."	Bidirectional
Hybrid	"To save space"	Left-to-right
Calculate	"The rest is just math..."	Left-to-right

Table 3.2: *Summary of categories identified in textbooks, including operational articulation used to identify type, example and direction in which equations containing this type of sign are most easily read.*

3.5 Results – Phase one: Textbook

Sixteen hundred and seventy-six separate equal signss were identified and coded in the five physics textbook chapters studied, an average of 335 per chapter. The distribution of usage by category for each chapter is shown in Fig 3.2. Textbooks are listed in order of increasing content level, from beginner (bottom) to most advanced (top). All bars are normalized to 100 %, with numbers overlaid to indicate the real numbers of codes in each category.

Introductory and intermediate textbooks (bottom three rows) show a higher proportion of simpler, *assignment* type equal signs, with (on average) 69 % of all equal signss found of this type. These texts also have more example problems than advanced texts, and the quantitative nature of such problems as well as formulaic, step-by-step explanations contain significant portion of both the purely *numerical* (e.g. $t = 5$) and *symbolic* (e.g. $F = mg$) *assignments* observed. Upper-level textbooks have a significantly smaller (average 43 %) percentage of *assignment* statements.

Surprisingly, advanced textbooks have twice the fraction (26 % vs. 13 %) of signs classified as *calculation*. The complicated derivations found in upper-level textbooks involve a high amount of symbolic manipulation, and hence include a large number of equal signss of this type. The derivations also rely upon more carefully defined quantities, and so have a larger fraction of *definitional* equal signs. The upper-level textbooks also have a surprising

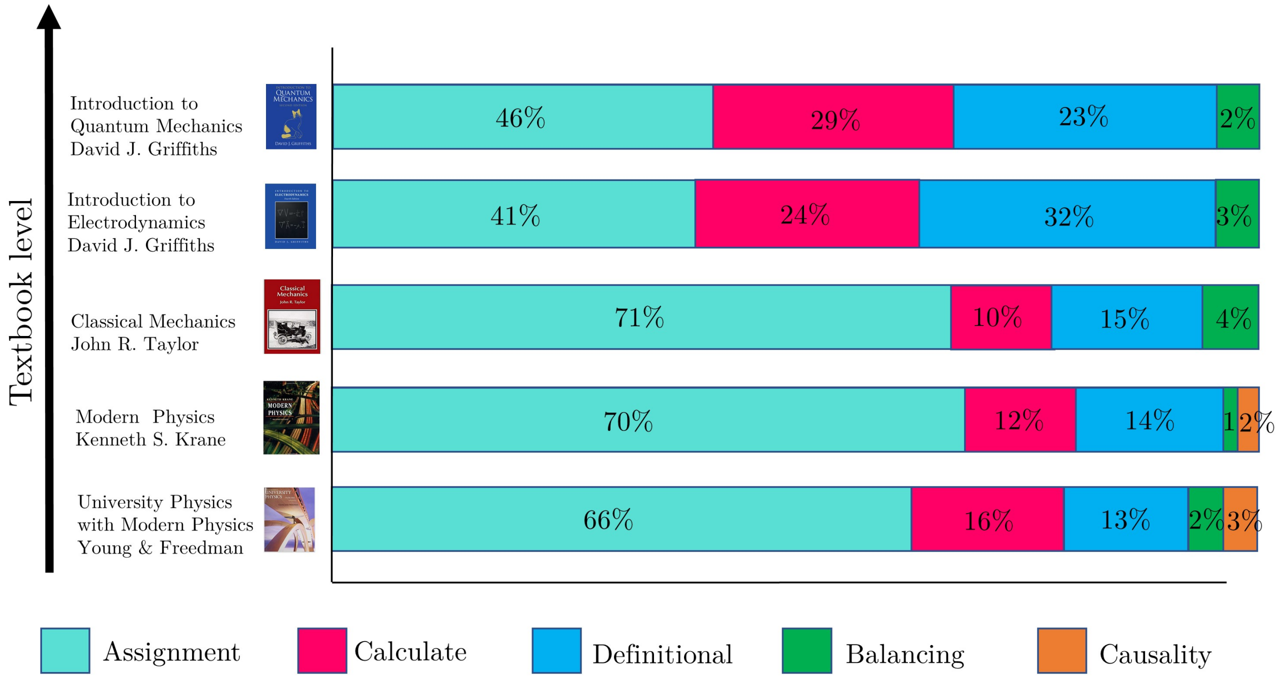


Figure 3.2: *Frequency of each categories across five physics textbooks.*

dearth of *causality* equal signss, even controlling across content.

In addition to a shift in the frequency of category types used, there are also changes in the sub-type of *assignment* signs as the material becomes more advanced. Introductory textbooks have a roughly even distribution of usage between *symbolic* and *numeric assignments*, a consequence of the many worked problems with numbers given. Intermediate and advanced textbooks, however, use far greater proportions of *symbolic assignments*. The intermediate *Mechanics* textbook[119] had a 10 : 1 ratio of *symbolic*-to-*numeric assignment*-type equal signs, where the advanced *Electricity & Magnetism* book[104] had a 22 : 1 ratio. Even when sample problems are present in these texts, the use of numbers is discounted in favor of more abstract, symbolic representations. We haven't found *hybrid* type of equal signs across our first data set.

3.6 Phase two: Meanings of the equal signs in upper-level undergraduate problem-solving[2]

3.6.1 Data Selection: Homework

The phase two of the project, we apply our classification scheme, which described in section 3.4 to look at students' solution in instructor-generated problems and then compare textbooks' problem solutions with that of students' solutions. Two sets of data are drawn from an upper-division course in an Electromagnetic Fields (E&M) at Kansas State University. This course is available each fall and typically covers the first half of Griffiths' textbook[104] (the most popular book in the US market for this course). The 50-minute class meets four days a week and is composed roughly of equal parts tutorial, group problem-solving, and interactive lecture.

Our first data set is composed of students' written homework solutions. Homework in this class contains problems drawn from the Griffiths' textbook as well as other sources, such as instructor-generated problems. The second data set is composed of the "official" solutions to a subset of those problems from the Griffiths' textbook solutions manual, augmented by additional problems in the solutions manual that were not assigned in class. For both data sets we first applied and amended our classification scheme. Once a stable set of categories was in place we invited additional researchers to separately code students' solutions. These researchers applied the categorization scheme to a randomly selected set of 10 % of the entire data set. The inter-rater reliability testing resulted in a 63 % agreement. After subsequent clarification and refinement, we repeated this procedure with an additional 20 % of the data set and reached 100 % agreement.

[2] This analysis was published in the Proceedings of the 2018 Physics Education Research Conference[123]

3.7 Results – Phase two: Students' written homework

The context of this study is an Electromagnetic Fields (E&M) course at Kansas State University. To begin the study 30 problems drawn from 11 problem sets throughout the semester were coded. The data were coded consisted of instructor-generated problems and Griffiths' textbook problems[104]. We selected problems to have broad range of topics in the course with non-trivial solutions likely to contain multiple types of equal signs. Three student solutions per problem were chosen. Criteria for these selections included legibility, correctness of solution, and sufficient difference from the solutions manual to preclude blind copying.

The equal signs can represent different ideas depending on the ways in which students use them to solve problems. Students used many representations (words, graph, equations, etc.) and different problem-solving strategies to solve similar problems. We find that students are most likely to use just three types of equal signs while solving E&M homework problems: *definitional* (D), *assignment* (A), and *calculate* (M). We only found two *hybrid* (H) equal signss among all responses, thus we ignored that type for this portion of our analysis.

Students rarely use *balancing*, *causality* and *hybrid* equal signs while solving E&M problems. We suspect that this is a consequence of both the course level and problem-solving process. Our textbook analysis 3.5 suggests that *causality* equal signs are more prevalent at the introductory-level and students may mirror dialect from the textbook.

Students vary in their problem-solving strategies. Some skip mathematical steps while others include each step in great detail. The latter mostly used one kind of the equal signs several times in sequence. The statistical order of appearance of equal signs is represented graphically as purple and green arrows in Fig 3.3 show the directionality of movement, with the arrow thickness indicating the relative frequency of each use. The curved grey arrows indicate successive uses of the same sign, while the thick arrows in *assignment* and *calculate* show their predominance.

Students more often move from *definitional* to *assignment* to *calculate*, a clockwise motion (purple arrows) as represented in Fig 3.3. Students begin solving a problem by translating the problem statement into a symbolic form, then recall equations, apply the conditions of

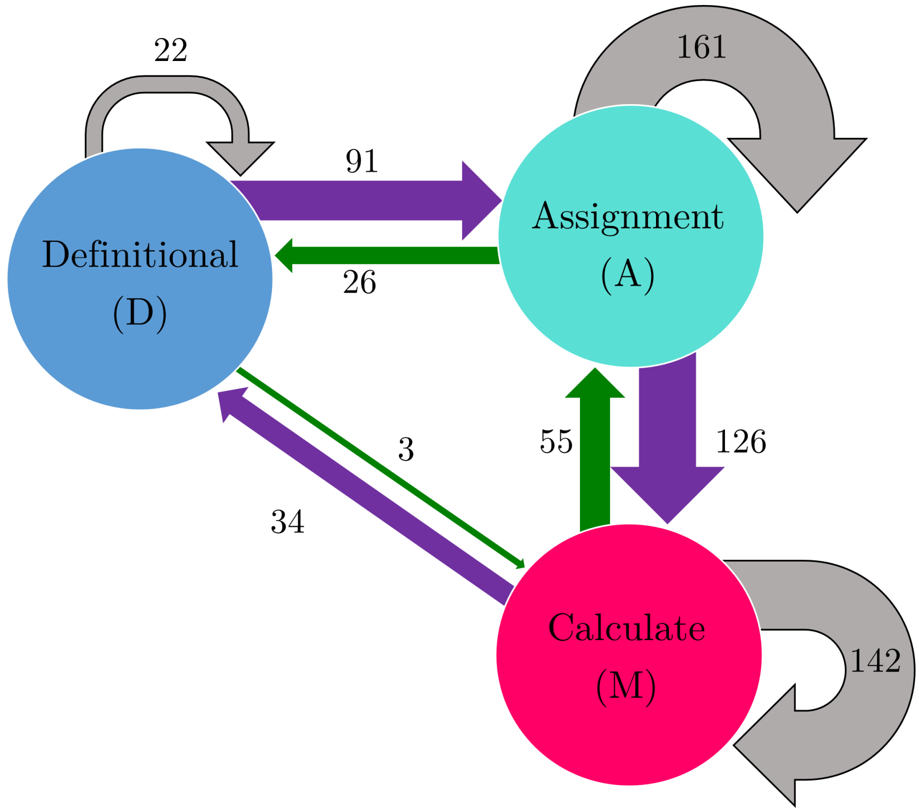


Figure 3.3: *Students' movement between different categories.*

the problem and, finally, solve the problem.

3.7.1 Comparison to solution manuals

We noticed that students' solution of instructor-generated problems is qualitatively different compare to students' solution of Griffiths-generated problems. Students have plenty of previous knowledge and ideas that they bring together when solving physics problems. We investigated further to see if the students' solution of Griffiths-generated problems are similar to Griffiths' solution of Griffiths-generated problems. To achieve this, we started study two, which is comparing the students' solution of Griffiths-generated problems with Griffiths' solution of Griffiths-generated problems. We can then compare the performance and see how closely students' solution aligned with the Griffiths' approach.

The second data set is derived from the textbook solutions manual to homework problems.

There is a total of 12 homework problems drawn from the Griffiths textbook, with each problem consisting of two to four sections.

In comparison to students' solutions the solutions manual's solutions are much shorter, with fewer steps compressed into a smaller physical space and less verbal narration or use of multiple representations. In some problems Griffiths explains the problem statement in text and recalls equations from previous problems. The majority of solutions are more abstract than those of students. Like the students, Griffiths uses *definitional* (D), *assignment* (A), and *calculate* (M) equal signs more than other categories.

One difference between Griffiths' and students' solution is the *hybrid* type of equal signs. Students solve similar problems or use the same mathematical steps several times, so they can simplify the procedure and solve using heuristics to obtain the final answer.

Fig 3.4 shows the frequency of each path between students' solutions and Griffiths' solutions manual. There is asymmetry between MD (*calculate* to *definitional*) and DM (*definitional* to *calculate*), MA (*calculate* to *assignment*) and AM (*assignment* to *calculate*), etc.

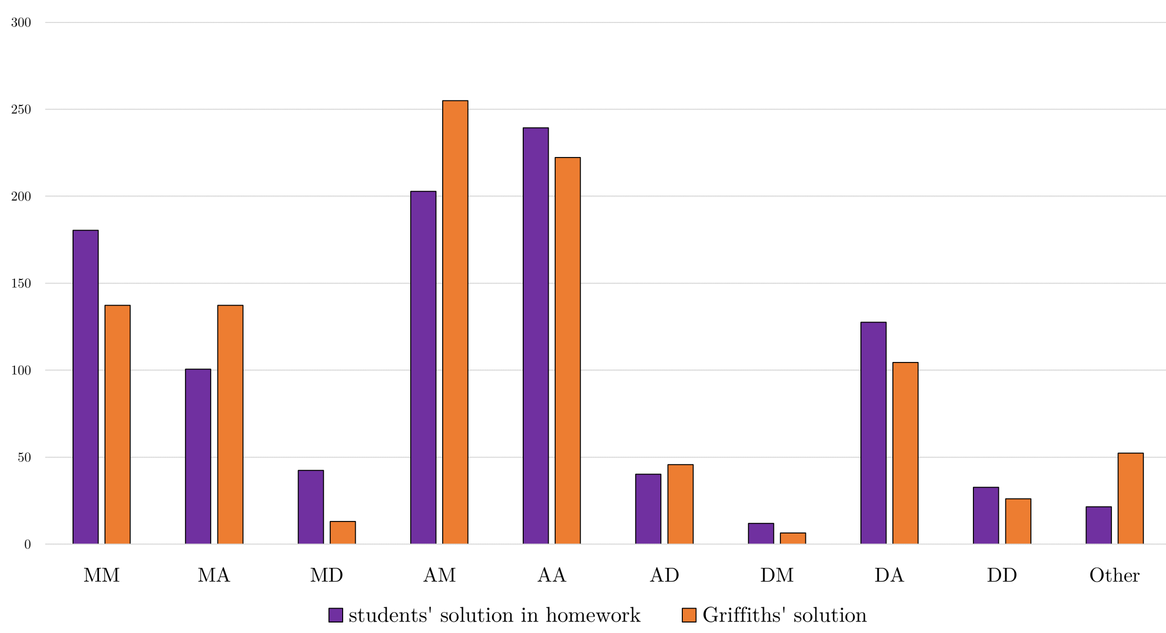
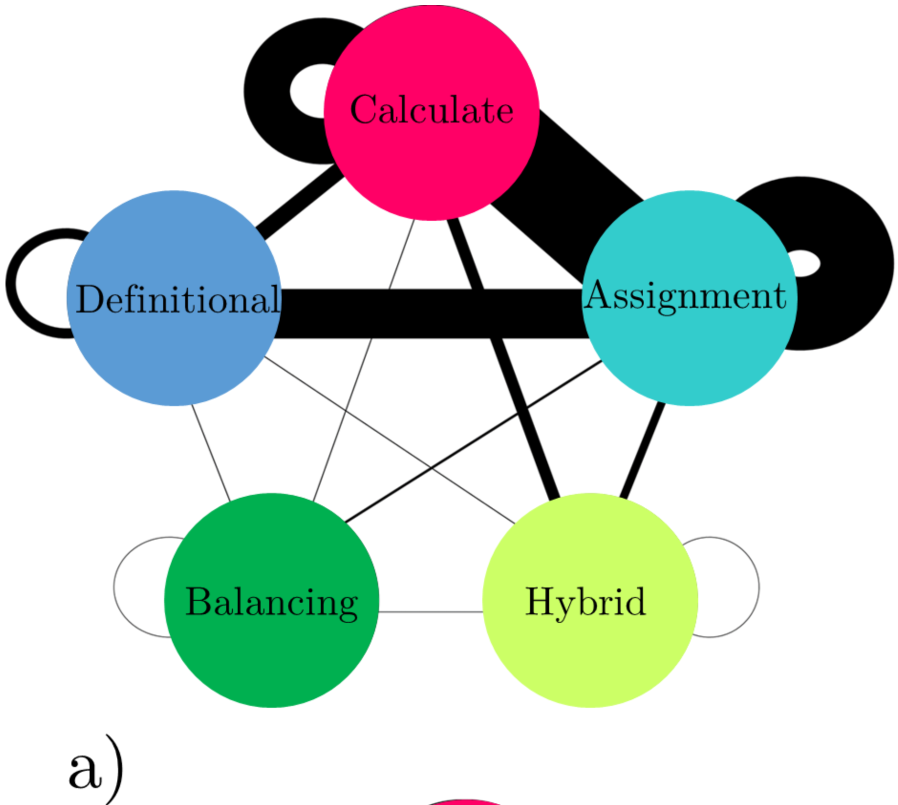


Figure 3.4: *(a) Students' solution network and (b) Griffiths solution manual's network.*

Across our corpora, we notice the *definitional* type of equal signs usually appears at the beginning of the solution, followed by *assignment* and *calculate* types. We can see students are consistent in their approaches to solving problems with similar structure. This asymmetry is more apparent in Fig 3.3, where we have represented directionality. These results demonstrate that students and Griffiths both prefer to make transitions in a clockwise rather than counterclockwise sense in this diagram, for example, DA is bigger than AD.

We use network analysis[124] to compare usage patterns of both students' and Griffiths' solutions to represent the relationships between categories and the steps of problem-solving. In our networks, shown in Fig 3.5, nodes indicate different categories of equal signs while edges indicate sequential usage which we interpret as interactions between types. Figure 3.5 includes self-connections for each node indicating sequential uses of the same sign. There are two types of network, directed and in-directed.

We use the idea of centrality to gain insight into the relative importance of the nodes (equal signs types). Centrality analysis characterizes the structure of the relationships between nodes within the network to see which nodes are most "important" or "central" to a network. We consider three measures of centrality: degree, closeness, and betweenness. Degree centrality identifies nodes with the largest number of ties to other nodes, betweenness is a measure based on shortest paths, and closeness measures the mean distance from a node to other edges.



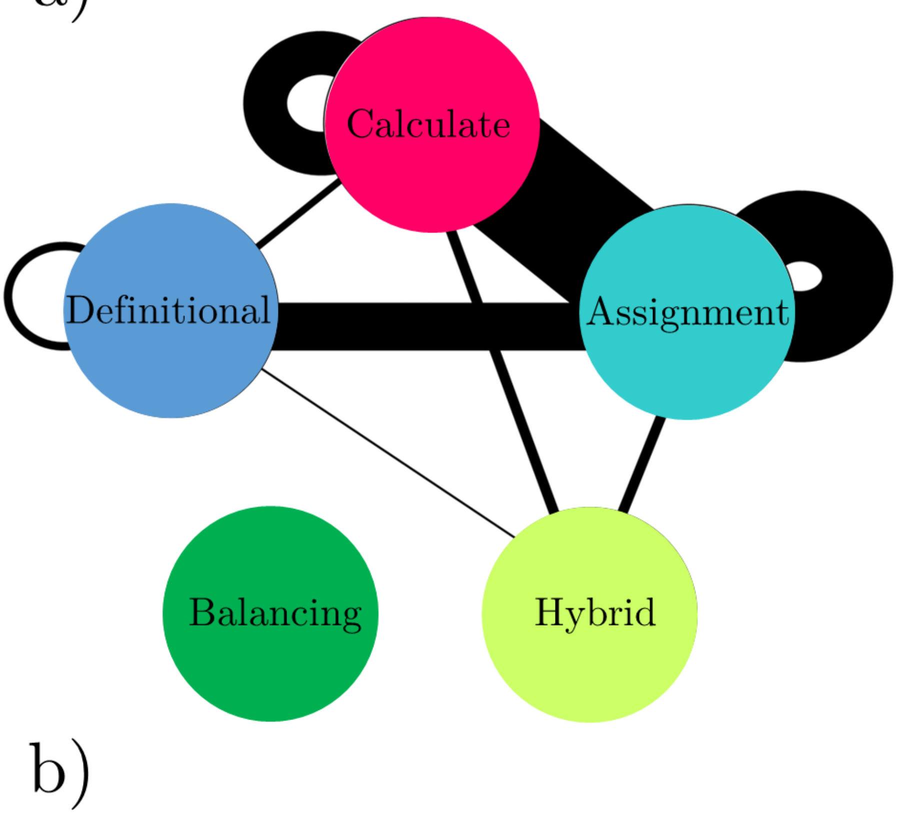


Figure 3.5: *(a) Students' solution network and (b) Griffiths solution manual's network.*

Several features are represented in these networks. Figure 3.5 indicates that even though students took many different approaches to problem-solving, the connections between *definitional*, *calculate*, *hybrid*, and *assignment* are more important than other categories. Furthermore, Griffiths tends to omit some mathematical steps, resulting in a less connected graph, yet the relative connections are similar. We note that students utilized the *balancing* type while Griffiths did not. Students' process of generating knowledge, their writing style, and the way that they sorted ideas in E&M provided them some *balancing* type of equal signs which we rarely saw in Griffiths' solutions. Griffiths' solutions have a clear mathematical explanation, which do not include the *balancing* type that can help students to understand the physical concepts.

Also, Figure 3.5 shows that the *assignment* node has many links in both networks, thus a higher centrality degree for both in-degree and out-degree. The closeness centrality usually implies that all paths should lead from a node to everywhere else. It is clear that *balancing* in Griffiths' network and *balancing* and *hybrid* in the students' network are far-removed from the rest of the network. With this more complete measure of betweenness centrality, the *assignment* type of equal signs is the most important node in both networks, with the *calculate* equal signs less important.

Since each problem has several parts, this can be the evidence that both students and Griffiths may have to go back and check their prior solution. Then, in the next part, they can assign the value in to the next part and calculate final answer.

Overall, the students' solution component is largely the same with Griffiths' solution across Griffiths-generated problems. The students largely performing the way that a normative expert suggested they should perform.

3.8 Discussion

We have presented an analysis of the use of equal signss "=" in physics textbooks. A categorization scheme was developed and validated internally for consistency among researchers as well as externally for resonance within the discipline. Six different categories were identified, with *symbolic* and *numerical* sub-categories also appearing.

Our categorization scheme supplements Sherin's symbolic forms[4;5]. Whereas Sherin ascribed meaning to entire equations, we argue that, at least in some equations, the meaning is mediated by the type of equal sign used. More broadly, we posit that the embedded conceptual meaning is contained specifically in the mathematical operators (symbols for addition, subtraction, multiplication, division, integration, differentiation, etc.) as these define relations between physics concepts. This meaning depends on the quantities being related (e.g. $F = ma$ has a different conceptual meaning than $F = mg$) and the difference is expressed in the relation, i.e. the operational symbols.

Understanding the equal sign as a relational symbol is more important in upper-level courses when both instructors and students solve more physics equations. They need to have an accurate perception about the equal signs in order to solving the word problems. They usually start with the problem statements in order to represent the information, use equations, and find the solution. This study has given us a first look at what undergraduate level physics textbooks mean by the equal signs. Evidence indicated that these textbooks use more simple and operational type of equal signs, however advanced textbook has a greater proportion of symbolic assignments rather than *numeric assignments*. Hence, as an instructor, if we want our students to perceive the equal sign as a relational symbol then more support is needed at an intermediate level.

In the second phase, I explore students' use of equal signs while solving problems in an undergraduate level physics E&M course. Then, comparing students' solution to Griffiths' solution shows allows us to check if their solution paths are similar to a normative path, while analysis of their solutions to problems outside of Griffiths helps us describe their solutions absent (ubiquitous) solution manual solutions. Network analysis indicates that the most important type (node), common in both students' and Griffiths' solution, is the *assignment* type. While the particular procedural steps differ across students and problems, this result is robust.

These results highlight the importance of understanding how undergraduate students think about equality and use the equal signs. As the use of equal signs is one indicator of the dialect of math used in physics, we can explore differences in how students, textbooks, and instructors use this indicator to better study the grammar of math in physics.

Focusing attention on the structure of the equations involving the equal signs leads to an understanding of an equation's underlying meaning which can help illuminate the dialect of mathematics used in physics. This could help drive students' conceptual understanding instead of equation memorization. Finally, thinking more deeply about the equal signs may help instructors consider alternative presentations of equations.

We emphasize two limitations in our projects. First, the focus on the equal signs intentionally ignores other symbols as indicators of dialect. Second, we emphasize the importance of context in our interpretations, and classification of a particular symbol depends sensitively on its relation with the surrounding text and other equations.

Chapter 4

How groups of students frame discussion in Physics[1]

4.1 Introduction

Over the past few years, the field of Physics Education has seen substantial research on problem-solving[12–14;16–19]. Research into problem-solving in physics aims to build theoretical models around how students solve physics problems, both alone and in groups, ranging from textbook-style problems to research projects. The accumulated knowledge includes conceptual frameworks to characterize students' reasoning in problem-solving activities. For example, a student may frame a learning activity as an opportunity for making sense or as an assignment to fill out a worksheet[100].

Students' epistemological framing has been investigated to influence their problem-solving strategies[8;126;127]. Knowledge in Pieces (KiP)[1–6] is an epistemological perspective to characterize and understand students' epistemological framework in the classroom in order to assist them in learning physics concepts more deeply. Knowledge in Pieces is a broad theoretical framework that has had significant success in realizing how students develop an understanding of physics.

[1]Part of this analysis was published in the Proceedings of the 2019 American Educational Research Association (AERA) Conference[125]

In Chapter 2, I used the resource theory from the family of Knowledge in Pieces theories to describe student' reasoning in upper-division E&M data[1–3]. Under the same set of theories, in Chapter 3, I used the Sherin's symbolic forms[4;5] to links mathematical equations to intuitive conceptual ideas in order to understand an equation's underlying meaning.

In this Chapter, we were still characterizing two kinds of students' epistemological frames under the family of KiP theories: answer-making[128–131] and sense-making[122;128;129;132–144]. We focus on evidence of students' collaborative behavior framing to identify specific markers that indicate whether students are engaged in the sense-making or answer-making frame. We also present preliminary results on how often students transition between these frames in topics of electrodynamics.

4.2 Theoretical framework

A growing body of literature highlights how students frame their activity while involved in a problem-solving process[7;96;97]. We have reviewed the literature on how physics students' epistemological framing has been changed over the activity in the classroom[7;9;99].

The concept of framing is borrowed from Goffman's Frame Analysis[91]. He studied people's expectations about their activities and found how these expectations influence their behavior to answers the question of " What is it that's going on here?"[94]. In the classroom setup, students use framing to make sense of the problem-solving activities that they are engaged in[91–93;98;145]. In the problem-solving process, students take cues from the different resources (e.g. problem statement, their group mates, and the instructor) to initially frame a problem[7;35;89]. We illustrate these differences by presenting to specific markers in each framework shown in Table 4.1. The analysis of the video transcripts revealed our categories that describe students' approaches to solve physics problem.

Researchers in science education have recognized the importance of students' seeking of ideas in the classroom. To describe the approaches that students use in class activities to make sense of physics, researchers have used the epistemological frames[6–9]. In this Chapter, we consider two epistemic frames which are common in students' discussions during problem-solving in group: sense-making and answer-making.

4.2.1 Sense-making

In reviewing the literature on sense-making, it is hard to find a coherent definition. We picked the definition of sense-making based on epistemological perspective. According to this definition, students frame their activity as *"figuring something out"* [8;130;143;146]. For example, when student finds a solution to a problem by connecting parts of that problem to other concepts and experiences in order to resolve a gap or inconsistency in one's understanding.

As Chen *et.al.* [129] have pointed out, "Behaviors associated with sense-making include making connections to the real world or lived experience, coordinating multiple representations, considering the reasonableness of solutions, and treating the problem as a sensible one to solve."

Sense-making is an expansive frame that generalizes ideas and connects those ideas across contexts and modalities [126]. In this frame, students spend a considerable proportion of time in qualitative arguments, including discussing physics concepts, planning solutions, and coordinating different physical laws. Instructors in this frame often productively participate in students' discussion by asking open-ended questions, and support students' expansive framing of the problem at hand.

Example: Sense-making

In this example a group of four students ("Leo", "Matt", "Jacob", "Ed") review a tutorial. Problem asks students to determine a purely mathematical expression for the volume charge density ρ of the beam line. Leo, Matt and Jacob work together quickly to solve the problem, while their forth group mate (Ed) stays silent during the problem-solving process.

Leo tells the group that he gets $\frac{2\pi r L\sigma}{\pi r^2 L}$, which is correct geometrically. Then he tries to evaluate his final answer by discussing to other peers. The group continues with different ideas, until Jacob says,

Jacob: Hang on! We still doing like a surface charge. Right? But it (the problem) wants a volume charge density.

Leo initiates the discussion by saying the volume charge density is the total charge of the volume and it is surface charge multiply by the surface area, divided by the volume. The group focus on how concepts are related to each other.

Matt: But, there is no volume.

And Leo quickly replies that the volume is the volume of the cylinder. Jacob disagrees.

Jacob: But, it is an open cylinder, I am pretty sure.

To support Jacob's idea, Matt suggests they need to find out the volume charge of the surface. The group plan outline to analyze and solve the problem. But, Matt confused,

Matt: Because the surface charge is kind of two dimensional, while the volume charge density is three dimensional.

They use argumentation as a tool to create the physical knowledge. With this reasoning, Leo erases his solution, because he was thinking about the entire cylinder volume, and now with new assumption he thinks using of the delta function might make more sense. As you notice in this piece of data this group spends a considerable amount of time in qualitative arguments to plan solution, develop a deep understanding of the problem to find out how they can change something from two dimensional to three dimensional.

4.2.2 Answer-making

In this frame, students and instructors both seek only to answer the problem in front of them. Answer-making is a narrow frame[126]. Answer-making, discussion is usually brief, focused on specific procedures or numerical calculations, and interspersed with long periods of students writing solutions. Although students in the sense-making frame frequently employ qualitative arguments, students in the answer-making frame focus on the detailed minutiae of the problem and memorizing a pieces of information[129–131].

Moreover, the instructor in the answer-making frame encourages students to focus on the procedures to find the final answer rather than any conceptual justifications. Instructors focus on answer-seeking with close-ended questions in order to lead them to the final answer, such as:“Do you need a minus sign in front of your integral?” or “Are you using a correct equation?” While sense-making can sometimes feel far-ranging and unfocused, answer-making is quite focused on the problem at hand and progresses towards an answer.

Even within prior work on sense-making and answer-making in physics, these two frames have been considered wholly different stages of problem-solving. For introductory or trivial problems, this may be true. However, it does not accurately represent either advanced undergraduate problem-solving or professional problem-solving.

Example: Answer-making

In this example a same group of four students are writing the curl expression in Cartesian coordinates and obtain the curl of a given field.

After hearing the instructor’s talking about curls in all three coordinates, the group decides to focus on instructor’ idea and approach the solution by writing down the curl formula in Cartesian coordinates from their notebooks. The instructor introduces the problem and she is writing down the equation 4.1 on the board.

$$\nabla \times \mathbf{F} = \begin{vmatrix} \hat{x} & \hat{y} & \hat{z} \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ F_x & F_y & F_z \end{vmatrix} \tag{4.1}$$

The instructor says the curl is equal to determinant of this matrix. Then, she asks students to solve the problem. She asks students to focus on the procedures to find the final answer rather than any conceptual justifications. Students start working independently for a while, they are in a writing mood rather than discussion mood. Later, Jacob asks Leo how to solve determinant mathematically. Immediately, Leo shares his solution with Jacob and briefly tries to justify his reasoning. Matt interrupts him and says:

Matt: So, when you have this, it is like this minus this, this minus this and the last one is flipped this minus this.

Matt only focuses on algorithmic steps. This kind of thinking is generally more answer-making. With this talk, Jacob starts rearranging the expression and he finds out that the second term is flipped instead of last term. Generally, the group focus on numerical calculations and checking the error.

Jacob: I think the second one is flipped.

The instructor has paused the problem-solving session and presents a field. She asks if everybody at the table agrees then students find the curl of the given field, which is,

$$F = xy\hat{x} + 2yz\hat{y} + 3zx\hat{z} \tag{4.2}$$

Matt tends to have less discussion and instead of that focus on writing a solution.

Matt: So,let's find the curl.

Students start working independently again (limit communication) and after some minutes, Matt checks the final answer and provides some help to Ed in solving the determinant mathematically. Finally,

Matt: You have that equation, and you know you can look at that and I just write it down, so I just had it in my notes, so I can say how to do this.

Obviously, Matt treats the determinant more mathematically. He recalls an equation, substitute the values and solve it. Jacob also double check his final answer to make sure he gets the correct answer.

Jacob: All right! So, xyx̂ xyẑ, cool. They are reviewing their final answer, when the instructor comes to the table to see the group's progress.

Instructor: You guys all have a same cross product?

She asks them about final answer to make sure that all the member of the groups has a same answer.

Matt: We did cross product, I did this operation on that equation.

And get the instructor's approval for their answers. By watching that part of episode, we realize this group spends more time in answer-making frame.

4.3 Methods and data collection

Much research in science education views sense-making and answer-making as a dynamic frames. In this Chapter, I provided a case study of two groups of students working on E&M course problems. I wrote content memos using a phenomenological approach. I abstracted the categories of students' behavior by reflecting on those content memos. I then connected these categories to ideas in the research literature around sense-making and answer-making. I posit that productively solving difficult problems in physics requires that students use both frames, and that they coordinate frame changes repeatedly throughout their problem-solving process.

I analyzed video-based class observations of an upper-division undergraduate E&M class to discover if students are in the sense-making or the answer-making frame (or neither). These videos have a possibility to give me a realistic sense of how tutorial works in natural setting and show the great verbal interaction among peers and between students and instructor. Groups of three to four students solved problems collaboratively on shared table-based white boards for almost all class sessions and for most of each period. This setting is a remarkably collaborative environment in which students work well with one another. The class session took place in a lab studio. There were three different types of situations in each session: multiple problem-solving, extended problem-solving and tutorial. In first two cases, students spend their times on solving problems on a single topic (short problems and long problems). My study involves four white, male students "Jacob", "Leo", "Ed", and "Matt", solve tutorials in a small group. Ed is quiet and barely talks.

This course consists of instructor lectures, a sequence of tutorials designed by the PER group at the University of Colorado Boulder, and homework. A tutorial is an active-learning worksheet which design to help students build concepts gradually.

I analyzed the group's discourse and gestures to each other[147–149] in order to categorize their framing as sense-making, answer-making, or neither (off-topic, listening to lecture, etc). In order to analyze the data, I started watching the videos from Fall 2013 at Kansas State University, in which students solve E&M problems. I analyzed students' data based on their discussion and technical quality, like clearly visible and audio is loud enough to be heard. For each episode, I watched the video several times, noting specific behaviors and discourse markers that suggest students' framing.

For this purpose, I am not interested in just the final students' answers, but I am interested in the details of students behaviors in problem-solving as a group. I look at students' discussion, characterize the cluster of behaviors that correspond to each frame as well as causes for transitions between those frames and argue that productive problem-solving may occur in any of these frames as long as students transition appropriately between frames. In result section, I provide evidence for how students within one group transfer between frames.

4.4 Results

I present two brief episodes to understand how students solve E&M problems in real classroom setting. Using the lens of the epistemological framing, I investigated two frames in our observational data: sense-making and answer-making. I focus on the analysis of two small discussion in one group of four students ("Jacob", "Leo", "Ed", and "Matt"). From the transcript, I analyzed the moment-to-moment thinking of each student. Observing how a student's framing shifts as a result of other group members' framing is beyond the scope of the current project, but will be a focus of future work.

In the first episodes, I found evidence that within one group students unpack their reasoning to solve some part of the tutorial, designed by the University of Colorado Boulder. This part of the problem asks students to determine a "purely mathematical expression" for the volume charge density ρ of the beam line as shown in Fig 4.1.

Leo decides to talk through the outline of his solution to the problem with his group. He starts the episode by telling other members that he didn't use a delta function to solve this part of the problem. Matt seems confused about Leo's solution, because he assumes they need to use delta function to be able to solve this problem. He asks Leo about his final answer for the previous part (which is related to this part) to understand "how do you know that your solution and final answer is correct?" He tries to understand Leo's procedure.

i. Determine a purely mathematical expression for the volume charge density, ρ, of the beam line.

ii. Check your answer by integrating to find the total charge for a length L of beam line. (Are the units correct?)

iii. What are the units of your delta function in (i.)? (This is another way of checking your answer to (i.), so don't only use your answer to (i.) to check the units.)

Figure 4.1: *Tutorial two designed by the University of Colorado, Boulder.*

Leo, using hand gestures, explains that when he solved the problem, he was thinking about charge on the cylinder. Jacob adds that charge on the cylinder were restricted to the radius of the cylinder. Leo continues telling the group that because delta function is a squeezing function, he gets $\frac{2\pi r L\sigma}{\pi r^2 L}$ as a final answer. Jacob concentrates on final answer, he says we need to integrate it to get the answer. Both Leo and Jacob spend a short time in both frames try to understand the conceptual physics and mathematical procedure in this problem as they move forward through Leo's solution. After eight seconds of silence, Jacob points to Leo's solution and asks,

Jacob: Are you coming up with a numeric answer? Is that numeric answer that I have seen?

We believe Jacob is looking for a numerical final answer to evaluate his solution. He wants to to find out if the answer is correct. Leo continues immediately with explaining that he gets $\frac{2\sigma}{2.6}$, which is correct geometrically. At this point, Leo mentions that he has no idea what is "the meaning of purely mathematical in this problem". He seems confused.

After a long pause, Jacob says he thinks they need to solve problem by using a delta function because next problem asks them to integrate the answer to find the total charge for a length L of beam line, "so, definitely it has to be delta in somewhere". He tries to make connection between the current situation and next problem and understand the problem as a whole. We believe that he is in the sense-making frame at this moment.

Leo disagrees, he thinks they can use his approach as long as they get r term in their answer. He tends to use his solution without conceptual justifications.

The group starts discussing by using their mathematics knowledge.

Matt: Well, no, integrating that over infinity [...] gives you 1.

Leo: Yes, but you have to r multiply by that, so it is evaluated just by r.

They use mathematics as a tool to check their understanding of the situation. The group working on their solution individually, until Jacob says,

Jacob: Hang on! we still doing like a surface charge. Right? But it wants a volume charge density.

Leo: Well, that is the only charge there.

Determining the volume charge density of the beam line is the most challenging part of the tutorial. After listening to Jacob, Leo initiates the discussion by describing that the volume charge density is the total charge of the volume and "It is surface charge multiply by the surface area, divided by the volume". He is in sense-making frame by using his hand gesture to display the volume. Matt comments that "there is no volume" and Leo quickly replies that the volume is the volume of the cylinder. Jacob shows disagreement,

Jacob: But, it is an open cylinder, I am pretty sure.

Matt: It is an infinitely thinned walled cylinder.

The students frame this situation as more sense-making and engage in a conceptual discussion. To support Jacob's idea, Matt suggests they need to find out the volume charge of the surface. We believe Matt is in the sense-making frame because he uses reasoning based on his knowledge of physics. He thinks the surface charge is kind of two dimensional, while the volume charge density is three dimensional. He looks confused again.

With this reasoning, Leo erases his previous solution. He was thinking about the entire cylinder volume, and now with new assumption he thinks using of the delta function might make more sense.

By lack of convincing argument, Leo and Jacob still have doubt about the cylinder's volume, and they refer to their knowledge that they have a bout volume charge on a surface. Jacob feels like the cylinder needs a cap on it. Leo says "in this case we don't need a delta function and his answer is correct". He backs up his claim that they can use his solution. The instructor visits the group at this moment of problem-solving. Matt explains to her that the problem asks for volume charge density, but the surface has no volume.

Instructor: Use a delta function!

The instructor does explicitly tell students how to get the final answer. Leo asks that do they need to find the volume density for entire cylinder or just for in shell?

Instructor The shell!

Later, when Jacob asks instructor about the meaning of a volume charge on a surface, the instructor focuses on the conceptual understanding to build a richer argument. The instructor asks students if they got annoyed in previous sessions, when they talked about a point charge on the line or not. She explains that they need to "use a delta function to have all the space". Leo quickly comes up with the answer that when they have all the space they need to squeeze it into radius. Leo and Matt discuss how the units works, including checking the right units and mathematical limitations. Later, Jacob participates in the calculation and explains to the group that they have Q on one side and ρ on the other side, what they need is flip it around. Leo and Jacob continue talking about more mathematical details and focus on algorithmic steps. All the students are in answer-making frame at this moment. They start with the triple integral. Both agree that they need something multiply by $dzd\theta$. Jacob thinks they need r, but Matt says the instructor is writing $rdzdrd\theta$ for the volume, he just repeats the instructor idea. The group continue their discussion until Jacob and Matt are checking the final answer on the textbook and make sure they get the right answer.

In the other episode of solving tutorial problem, students solve another tutorial, designed by the University of Colorado Boulder as shown in Fig 4.2. The problem given to the same group is about calculating the electric field at location $\vec{r}$ due to a charge $+Q$ at location $\vec{r'}$. The first part of the problem asks students to draw vectors for $\vec{\imath}$, $\vec{r}$, $\vec{r'}$ on the diagram.

At the beginning of the class, the instructor asks students to determine if $\vec{\imath}$ is equal to $\vec{r} - \vec{r'}$ or $\vec{r'} - \vec{r}$.

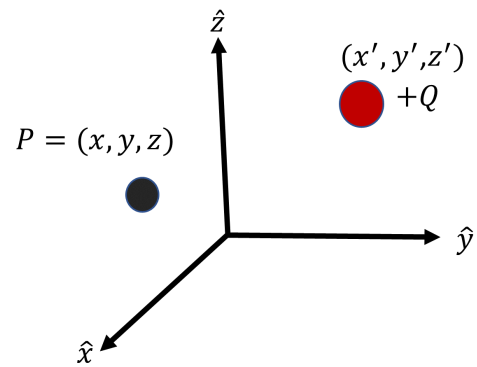
On Jacob first pass through the problem, he rapidly says:

Jacob: It should be $\vec{r} - \vec{r'}$.

There is a charge $+Q$ at the point (x', y', z').

We're concerned with the field at point $P = (x, y, z)$.

i. Draw on the graph: $\vec{r}, \vec{r'}$, and $\vec{\mathscr{r}}$ (where $\vec{\mathscr{r}}$ is Griffiths' "script r").



ii. Express $\vec{\mathscr{r}}$ in terms of $\vec{r}$ and $\vec{r'}$.

iii. Now express the Cartesian components of $\vec{\mathscr{r}}$ in terms of the Cartesian components of $\vec{r}$ and $\vec{r'}$.

Figure 4.2: *Tutorial one designed by the University of Colorado, Boulder.*

The instructor asks a closed question, and Jacob responds with an answer both to her question and the problem at hand. At this point, he does not go through all the steps of solving the problem. In contrast, Matt by using hand gesture, tries to develop a deep understanding of what Jacob says. We believe Matt is in the sense-making frame.

Matt: This vector minus this vector ($\vec{r'}$ - $\vec{r}$). It is the wrong direction, right?

Matt explains to the group that he thinks Jacob's answer is right by using his hands. He evaluates the result and moves on.

Jacob: Because we need a vector to point (he uses his hand to show the direction) that way and if you, ... (pause)

Jacob tries to explain his solution conceptually by using a hand gesture, for other members of the group, accordingly he is in the sense-making frame. Ed contributes briefly to the discussion.

Ed: So, we need to switch all of those to, ... (pause)

Matt: $\vec{r} - \vec{r'}$.

We interpret frame of Ed as the answer-making at this moment, because he is just looking for a final answer and communicate shortly. Due to Matt's answer, Leo thinks all he needs to add is a prime. This confusion continues until,

Leo: What is the convention for the direction of these?

Matt: $\vec{r'}$ supposed to point to the test charge. When it got their Cartesian coordinates, this is label this $(x'$,y', $z')$. In my mind it is better to keep the convention the same then keep the convention that she (the instructor) talked about it, so then if the script r is those from the charge to the test charge the direction is, I am back to done that? Now it makes sense.

This statement apparently motivated Matt to re-enter the problem by carefully revisiting the problem and builds a bridge across the gap in Leo's mind by using physics concepts and tries to qualitatively solve the problem without formal mathematics. Matt is in the sense-making frame. Jacob continues clarifying the details and check the final answer, he thinks about the starting and ending points.

Jacob: You know, when you just plotting a stuff on a regular graph, and you got your starting point any point you like to solve the line, you take the end of and it's gonna track with that start with. So, $\vec{r} - \vec{r'}$.

We believe Jacob spends some time in both frames. Overall, framing analysis indicates that students switch between sense-making and answer-making as they move forward through their solution. Figure 4.3 shows students' frame during a eleven-minutes of the problem-solving episodes.

4.5 Discussion

I presented two case studies of a group of students switching frames to productively solve E&M problems. However, previous research has generally focused on students' different frames separately, but did not consider how these frameworks are very close to one another. After watching and examining the details in students' behaviors, I sought to identify

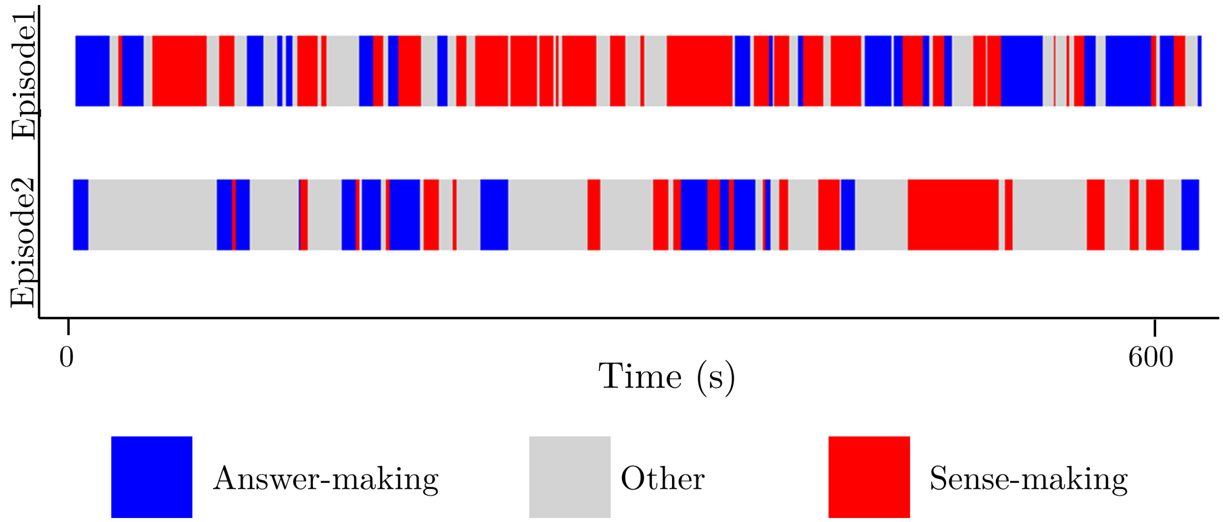


Figure 4.3: *Student framing during an eleven-minute problem-solving episodes.*

students' frames: answer-making and sense-making. In order to interpret the dynamics of students' problem-solving behaviors I looked at their transition between these two frames. By observing students' behaviors, I noticed moments that students change their attitude towards the problem to move forward in their activities. However the student's framework is affected by different factors, such as group setting work, tutorials, instructor roles, etc. is an interesting point that require more future research.

An important limitation of this study is the different factors which can affect students' framing. Students' frames are changed by a number of factors such as the wording of the tutorial or problem statements and instructor guidance. These factors need to be considered by physics education researchers.

Frame	Observed student behavior, students,...
Answer-making	repeat and focus on the instructor's ideas and follow their instructions.
	memorize an approach to solve a similar problem and use that memory to solve new problems.
	focus on algorithmic steps, such as stating an equation or substituting given values.
	point to the mathematical meaning of the equation, rather than the underlying physical meaning.
	limit communication: they contribute shortly, often writing down the solution.
	evaluate the final answer by concentrating on numerical variables.
	practice schooling.
	view the instructor as an audience and evaluator.
sense-making	Focus on how concepts are related.
	outline a plan to solve and analyze each problem.
	qualitatively solve a problem without formal mathematics.
	keep evaluating results or outcomes and moving on (retrospective).
	participate productively in open discourse.
	work to develop a deep understanding of the subject.
	build bridges across the gaps in their minds by using and interpreting physical concepts.
	refer to concepts to obtain solutions.
	use different representational tools.
	focused on the underlying meanings of the equations.

Table 4.1: *Summary of student behaviors that are associated with the sense-making and answer-making frames*

4.6 Summary

Many studies have investigated students' epistemological framing when solving physics problems. I used the knowledge in pieces theoretical framework based in epistemic framing that separates the students' epistemologies during problem solving in group into two frames: Answer-making and sense-making. Previous work on framing at the upper division level has investigated how students coordinate mathematics and physics ideas, and how students frame their problem solving as expansive or narrow. In contrast, work at the introductory level has investigated disparate frames around solving worksheets or discussing ideas. I used videos of students solving problems in an upper-division E & M classroom. I first characterize the markers of each frame, focusing on analyzing students' group frame. I presented a pair of examples that show how often students transition between these frames. I have demonstrated that productive problem solving requires both the answer-making and the sense-making frames.

Chapter 5

Summary and future work

All three projects in Part I have been discussed in their respective sections detailing the work, for brevity the detailed conclusions will not be repeated here. The central question of this part is concerned with the processes of problem-solving among upper-division students. I used three theoretical frameworks from the KiP family [1–6], as different lenses with which to view and analyze the data in order to understand how students think when solving E&M problems. The first two studies put more emphasis on the *content* of students' thinking, while the third study focused instead on the *process* of students' thinking when they are solving E&M problems. I adopted qualitative methods to examine the upper-division students in the context of problem-solving. The data for all of these studies came from the same students in an upper-level electrostatics courses at Kansas State University. For the first two studies, results are derived directly from the text data (such as written homework and physics textbooks). The last study focused on the interpretation of the interactions between students as a group, and the primary data source was videos of students solving problems.

First, it is helpful to discuss the motivation behind each study. I was particularly interested in learning about the content of students' thinking in E&M course. In the early stages, I began by looking at students' thinking in terms of knowledge elements in an individual's mind in order to understand the knowledge elements that students employed to build up knowledge about E&M problems. A knowledge element is a piece of knowledge that can exist at various grain sizes. DiSessa[1] proposed "phenomenological primitives", or "p-prims" for short, which are grain-sized knowledge elements that make sense to the students. Larger grain-sign knowledge elements have been discussed by Hammer[3]. Hammer[3] called all of the tools, knowledge, concepts, and beliefs that students use in order to solve a problem "resources". The main idea behind these theories is that a students' knowledge system contains many knowledge elements which are activated depending on the context. For instance, in Chapter 2, I found the clusters of *super-atomic* and *sub-atomic* resources were activated together when upper-division E&M students expounded on the behavior of materials in electric and magnetic fields. The findings of this study add to the body of previous research indicating that they way that students construct their own knowledge depends on the context. Furthermore, after watching videos of the lectures corresponding to my data about magnetic and electric fields, I noticed that the way that the instructor lectured was very different. For example, the instructor used more mathematical justification rather than physical descriptions of the way material behaves in high magnetic fields. The students' responses reflected this difference. Instructors can build on these *sub-atomic* and *super-atomic* ideas in order to help students construct more scientific explanations and complete their mental models.

Thinking cannot be formulated as something to teach. However, helping students to construct more complete mental models is a goals of physics teaching and learning. These findings proposed and opened new avenues to capture how students solve problems in upper-division physics courses. More research is required to facilitate students' problem-solving skills.

This work has implications for both future research and for instruction. For research, considering how resources are activated and whether these resources are more solid or more plastic could be a topic for future study. This is a tentative exploration that raises questions for future investigation about how much or what kinds of supports students need in order to activate more related resources during the upper-division E&M problem-solving.

We know that active learning environments paired with conceptual curricula improve student understanding of physics, but improved instructional methods are still needed to support students' reasoning in these areas, especially for upper-division courses. Finally, our work highlights the need for future research on students' use of resources to solve problems in these upper-division physics courses. We believe that thinking about polarization inside the atom seems to increase understanding and can give students better intuition about special cases such as dielectric breakdown.

This research yields multiple implications for instruction of E&M. After comparing the answers in Part A and B of the final question and watching videos of the lectures corresponding to them, we hope to encourage instructors to put more emphasis on *sub-atomic* conceptual models when teaching polarization. These implications for instruction can also apply to lower and higher level courses than upper-division E&M, and conceptual understanding of physical phenomena on a *sub-atomic* scale could be a helpful supplement to math based curricula as well.

I was also interested in the resources that students draw upon when applying mathematics knowledge to a physics context. The value of having an accurate sense about physics equations can help both instructors and students to have a proper understanding of the physical concepts and physics problems. I drew upon another theory from the big family of KiP: symbolic forms[4;5]. A symbolic form is a cognitive resource that is comprised of two components: a symbol template and a conceptual schema. Symbolic forms[4;5] generally have a bigger grain-size compared to p-prims and resources because they are compiled from other cognitive resources. In Chapter 3, I presented an analysis of the different physical meanings associated with the equal signs that can be inferred from introductory and upper-level physics context.

This work provide initial implications for both instruction and future research. For instruction, this study may help instructors to aid students in making connections between mathematics and physics. I do not recommend that instructors directly tell students about the different kinds of equal signs. Rather, I encourage instructors to apply changes in their curricula based on improving students' mathematical reasoning about the equal sign. For example, instructor can use multiple step problems to tell the students about the conceptual meaning behind the equations and equal signs while solving a problem on the blackboard in the classroom or giving a lecture. I believe that, repeating mathematics skills that students need to solve the physical problem can be beneficial for students.

In addition, we encourage instructors to provide opportunities such as collaborative problem-solving for students to foster their reasoning in the classroom and engage them in conversations about the equal signs. While an instructor can engage students in the collaborative problem-solving process, observing these students perform mathematical expressions and solve physics problems may provide a unique opportunity for instructors to explore their reasoning process. Moreover, such a collaborative activity may provide a learning environment enabling students to understand both the physical and mathematical reasoning behind the expressions.

Future work in research area could proceed along multiple lines for researchers. First, instructor discourse surrounding use of symbols during classroom practice could be investigated. Such work would identify how instructors attend to the conceptual meanings of symbols, with practical implications for instruction. Moreover, how physicists use equal signs in physics articles may value to consider. In addition to examining the formal written dialect of math in physics, we plan to expand our fundamental work to more informal spoken dialects as well.

Beyond understanding the content of students' thinking in E&M course, it is important that students who have various knowledge elements can apply them in problem-solving situations. I was curious about how students encounter and interpret the E&M problem-solving situations in a lab group setting. The concept of framing[94] helps to answer the question "What is going on here?" and to get more familiar with the process of students' thinking. I considered framing because it is a set of expectations that affect what students notice and how they think to act[6]. Working as a group sharpens students' awareness of their own ideas and other students' ideas. The results explained the process of students' thinking as a group: how they think, how they respond to each other's questions, and how they use different cognitive resources to solve the E&M problem.

This is a preliminary analysis presented in Chapter 4. Future work will continue to investigate student's framework which could be affected by different factors, such as group setting work, tutorials, instructor roles, etc. is an interesting point that require more future research. Although the results of our current study provide useful insight for informing physics practices in small group learning environment, there is still a need for future research to explore how instructors influence student's epistemological framing in their problem-solving.

For instruction, instructors can guide students who do not have the required resources and who do not use group settings effectively to understand the concepts more deeply. These results give insights into how both frames are important in group problem-solving activities and how instructors can use student strategies to inform their instructional goals. More broadly, supporting students' frames during problem solving process may have implications for curriculum developers.

These three studies all interpret how students are thinking and reasoning in an E&M course. The major difference among these studies are the theories which were used to analyze the data. I took the view that knowledge can constructed by individuals, analyzing students' individual homework in Chapter 2 and Chapter 3, and the social, as was done in Chapter 4.

Employing all of the theoretical lenses in Part I was very valuable. For instance, the process of thinking and reasoning among students results from activation of many resources. By knowing more about these resources, it may be possible to support students to think more productively in physics contexts. The first study revealed student cognitive resources. Similarly, the second study looked at how students apply cognitive resources in physics equations. I found that the most repeated resources are common in both students' solutions and solutions manual.

This work has provided better insight about how students use their knowledge elements to construct mathematical knowledge. It may be useful for students to see and hear their instructor's thinking in order to help them to construct their own mental models. Additionally, their beliefs, experience, and instructor can affect the kind of knowledge they activate and the way they attempt to solve the physics problems.

Our studies agree well with previous research based on p-prims, which allow students to make predictions and provide casual explanations. Additionally, I have found that students' current knowledge elements affect how they evaluate new problem-solving situations. For instance, our findings from the clusters of resources study (Chapter 2) guided our analysis in the students' framing study presented in Chapter4. Furthermore, the results from Chapter 2 and Chapter 3 promote our conceptual understanding around process of students' thinking.

Overall, if instructors want to be a positive influence on how students learn physics, they need to pay attention to how students think about physics concepts and how they use their knowledge to construct and improve their mental model to get a deeper understanding of a physics. Instructors must have a clear idea of their students' abilities and their own teaching philosophy in order to be a better instructor. They may need to adopt new instructional practices and implement changes as needed to meet the needs of their students.

The second central question in this dissertation is concerned with the processes of instructional change among physics instructors. The importance of the role of the instructor in the classroom is well established in physics education research literature. However, little research has been published about the instructors' actual needs in the classroom. Knowing the fine-grained details of instructors' experience around changes in their teaching might provide professional developers and designers a better understanding about their users an to design materials to help them in their teaching. The focus of Part II is to explore how physics instructors approach changes to their teaching and what the processes of instructional change among physics instructors looks like.

Part II

Processes of instructional change among physics instructors

Chapter 6

Review of related literature and studies for Part II

6.1 Introduction

The next central question in this dissertation is concerned with the processes of instructional change among physics instructors. The general framework behind this study is under a broad family of KiP[1–3]. I believe that, instructors have epistemological beliefs that can influence the results of their teaching. Epistemological resources usually appear as a cluster of activated conceptual resources[3]. To get a better understanding about instructors' needs, I require to investigate the teaching process in fine-grained detail so that I can develop descriptions of instructors' experiences around teaching with a focus on instructional change. Data are drawn from semi-structured interviews with twenty-three physics instructors, who made changes in their classroom. By analyzing the grained-size details of physics instructors' experience around making any changes in their teaching, we can characterize their goals, motivations, challenges, resources, and attitudes towards implementing new changes in their classroom.

In this chapter, I summarize the literature and previous studies that have informed my research. First, I review the research literature related to the professional development, which may vary from developing specific content knowledge to developing teaching pedagogy techniques. Next, I review the literature about educational change, which is placed at the core of the professional development process. Then I point out the limited voices in designing professional development programs.

6.2 Research on professional development

There is a consensus view in today's educational world that instructors are the most effective part of the classroom. They have the greatest effect on helping students learn. Some physics education literature encourages instructors to participate in different types of activities in order to support their lifelong learning and maintain the level of their professionalism[150–153]. Such a perspective views the instructor's professional development as an essential lifelong process of growth that cultivates new attitudes towards changes in their thinking and practices. Based on the importance of the instructor's role, professional development (PD) workshops have been increasingly used to promote the understanding of research-based instructional strategies (RBIS). Professional development workshops provide an opportunity of in-depth discussion about different teaching strategies[154;155]. Guskey[156] states that professional development aims to provide "systematic efforts to bring about changes in the classroom practices of teachers, in their attitudes and beliefs". Importantly, the recent literature found that the use of professional development workshops have a positive influence on adaptation of RBIS and achieve effective change in teaching practices[150;155–167].

While several authors argue for professional development effectiveness, some studies focus on the process of instructors' implementing changes to their teaching practices in relation to professional development. Although, they discuss moving from comfort zone to adventure zone could be a hard process for some instructors, professional development is an affordable and easy way to do it[168–170]. A review of the literature on professional development gives the impression of its complexity and different meanings. For example, Boyer and Crockett[171] talk about it as a part of organizational development, while Wergin, Munson and Faris[172–174], have defined it as a set of different instructional activities designed to help instructors. On the other hand, Rose[175] believes that professional development is almost anything that instructors do outside the classroom. Mayhew[176] outlined four criteria for professional development: assisting instructors, creating proposals, developing the ability to solve institutional problems, and improving talents in extending professional consulting services. He came to the conclusion that the primary purpose of instructors development is to improve their ability to generate revenue.

Another practical definition of professional development is defined by Francis in 1975. He describe it as "an institutional process which seeks to modify the attitudes, skills and behaviors of instructors toward greater competence and effectiveness in meeting student needs, their own needs and the needs of institution". Overall, many studies define professional development as a"successful implementation of any education reforms (change)[156;177;178;178–181].

6.3 Research on educational change

A review of the literature on professional development shows that "educational change" is placed at the core of the professional development (PD) process. PD is a continuous part of the process in educational change[182]. Before we tackle this study, we need to be sure we have basic agreement on the definitional of "educational change"? In the following paragraphs, several theories on educational change will be discussed briefly.

The complex term"educational change" is used in various ways by PD designers, researchers, policy makers, and instructors[183–191]. By taking a look at the history of this term, "change" can be interpreted as success or failure. It can also be defined as making something better. However, what "better" means is out of scope of this dissertation. Educational change can use as a term of "branch changes" such as adopting new instructional methods or making small decisions. Additionally, it can be use as a term of a "root changes", which is a deeper and larger transformation in instructors' work and school improvement[185;189;191–194]. The ultimate goal of school improvement is almost aligned with the goal of PD[195;196].

There is considerable literature on educational change, we will start with the works of Fullan[161;183;186–188;197;198] and Hargreaves[199;200], two influential scholars who have made important contributions to the understanding of an educational change. With the publication of the first edition of Fullan's work in 1982, he introduced the idea of educational change as a process to put something new into practice. His model focuses on "the human participants taking part in the change process" and discusses about how stakeholders act as change agents. In 2007, he divided the change process into three different phases or stages: Initiation, implementation, and continuation[197], which are all necessary to achieve educational goals.

Hargreaves researched educational change and asserted that any significant successful change in curriculum never happens, unless we pay serious attention to instructor development. He argued many factors inside the classroom affect instructors' perspectives about applying any changes. Hargreaves and Shirley[199], in their book, argue that three old ways for educational change – which defined global educational policy and practice from the 1960s – are no longer applicable. To solve this problem they have presented the fourth way. The fourth way is a theory of action, which "brings together government policy, professional involvement, and public engagement around an inspiring social and educational vision of prosperity, opportunity, and creativity in a world of greater inclusiveness, security and humanity to forge an equal and interactive partnership among the people, the profession, and their government." It is an innovative vision of educational change designed to meet the problems and challenges facing educators in the current century.

Instead of just concentrating of the work of Fullan and Hargreaves, we would like to review some other viewpoints that have critically influenced the definition of educational change. Some literature purports the interactions between members of the learning community as an essential factor in educational change context[201–203]. This literature also focuses on the sociocultural nature of leadership, change, and transformation in schools.

From another prospective, Senge[204] thinks that, it is impossible to change the learning organization before making a change in each individual in that organization. Hiatt[205] agrees with this idea around the change at an individual level. To further this idea, he developed ADKAR, which is a five step change management model that can assist in the development of a cultural transition program. Lewin[206] thinks about educational change from different perspective. He claims that educational change as a process that needs to happen over time.

Besides, Clarke and Hollingsworth[207] elaborate a framework based on interconnected model of instructors professional growth which called (IMPG) to explain the instructors' change need time. In order to understand instructors professional growth, the authors explain different domains and possible pathways through which professional knowledge can grow.

Wideen[184] identifies five domains of educational change: curriculum development, school improvement, school effectiveness, teacher research and teacher development. It is interesting to note that in instructor development domain researchers focus on the instructor as an active learner. Furthermore, Kwakman[208] suggests that to support instructional change researcher need to pay more attention to instructors cognitive aspects, such as their beliefs and preconceptions about teaching. Also, Duke[189] has synthesized various ideas regarding capacity for change and elements of a good design for educational change. Interestingly, Opfer *et al.*[209] argue about instructors belief, learning and highlight that instructors change is not a sequential process as suggested by other authors. According to Opfer *et al.* educational change depends on what instructors do and think.

Moreover, scholars are still interested in research on instructional change and instructors needs, in order to provide them more support during a change process[210–212]. In addition to defining change and examining professional development workshops, higher education scholars also investigate the process of instructional change from the influence of context (departmental and institutional) and talking about instructor needs[166;210–220]. For example, Henderson, Beach, and Finkelstein[212] review 191 journal articles encompassed STEM education research, faculty development, and higher education research. They identify that faculty change efforts typically fall into one of four categories: disseminating curriculum and pedagogy, developing reflective teachers, developing policy, and developing shared vision. Fairweather[221] asserts that instructional setting such as laboratory, lecture hall and recitation has a more important influence on the class outcomes than just academic discipline.

Reflecting on the literature, defining educational change and professional development universally is hard. Educational change researchers largely write about changes in large-scale view such as changing schools and the curriculum development, and small-scale view such as changing individual instructors. Some other research talk about different professional stages[222], however, there is a general agreement that instructors have different PD needs at different points in their professional career path[223].

In this study, we put our emphasis on instructional improvement. We define professional development as a set of activities to support educational changes and design to improve the total growth of instructors individually. Hence, we zoomed in on the individual physics instructors. Similarly, Gaff, Eble and McKeachie[224–231] emphasize the idea of growth and the process of helping instructors in their instructional roles and with teaching effectiveness. Gaff[224] describes that: "enhance the talents, expand the interests, improve the competence, and otherwise facilitate the professional and personal growth of faculty members in their roles as instructors". This is supported by Reeves[232], who states that if we expect instructors to improve their instructional roles, we need to provide them enough resources and required knowledge and skills.

6.4 Limited voices in designing professional development

There is no hesitation to conclude that professional development workshops like the Physics and Astronomy New Faculty Workshops (NFW) are important in addressing the instructors' improvement and increasing their knowledge of active learning strategies[165–167]. Although, some literature concluded that more evidences needed to claim the effectiveness of these workshops[233–235]. Professional development leaders may not give acknowledgment to the voices of participants when designing professional development. According to Feltcher[236], some professional development developers design materials without noticing about impact of those strategies in the real classroom setting.

Over the past two decades, vast research on the professional development focused on the evaluation of it, which has included a number of factors to help answer the questions of "Do professional development workshops are effective enough?", "Do professional development leaders observe the participant outcomes expected to derive after professional development workshops?", and "What are the perceptions of professional development experiences as perceived by instructors?". Less work has been done to support the exploration and analysis of different approaches to design[165;166;237–243].

Instead, I believe that listening to the voices of instructors and their epistemological beliefs toward teaching, could promote the view of professional development designers and developers. Similarly, Hunzicker[244] argues that, there is a lack of research about voices of instructors as a learners in the process of making decisions about professional development planning.

6.5 Summary

In this chapter, I discussed about professional development that comes in many forms and many levels. Also, I learn about the complex term of educational change, which is used in various ways by professional development designers. I want to focus on answering more specific questions to learn about how physics instructors are making changes to their teaching and their process of teaching more broadly.

I support this by a fundamental research on instructors needs around changes in their teaching. For example, "How they approach changes in their teaching?", "What are challenges they experienced when implementing a new teaching ideas?", "What are the common motivations and constrains which most physics instructors regularly have?", and etc. Knowing the answer of questions such as these may help professional development designers to create more meaningful and effective materials.

With this in mind, the specific professional development program in chapter 7 focus on is static online resources like PhysPort website (http://physport.org)[11]. It is a website from the AAPT (American Association of Physics Teachers) with teaching materials and lots of research-based assessment tools and resources. This website focus more on individual needs rather than the institutional needs. PhysPort includes overviews of over 50 research-based teaching methods and over 80 research based assessments (RBAs), along with the virtual New Faculty Workshop and the periscope collection of video-based TA training and professional development materials. It also includes expert recommendations with specific guidance on implementing research-based teaching and assessment, and the data explorer. From a Physics Education Researchers perspective, some research are conducted on instructors change has found that even highly motivated instructors aware of PER have trouble getting the support needed to implement PER-based teaching effectively. We believe that the PhysPort website can help those instructors.

As a part of research on developing resources to support physics instructors, we investigate how physics instructors approach changes in their teaching. In chapter 7, I will report a phenomenographic study on physics instructors approach changes in their teaching and how it altered their teaching.

Chapter 7

Phenomenographic study of physics faculty's instructional change

7.1 Research design

Anderson[245] states that most instructors have a great story to share about their teaching practice and their different classroom experiences. Instructors usually use a professional development program as a journey of improvement. The central research problem of this study does not include an exploration of new teaching methods, new strategies, and an understanding of major issues that have influenced instructors teaching. This problem is related to the research conducted in the field of educational change and professional development.

This project is part of larger, ongoing study on redesigning the PhysPort website[11] to make it a more coherent whole. As shown in Fig 7.1, the whole PhysPort research process defines in three components: PhysPort team interview physics instructors about applying changes in their teaching and assessment, then applied research on user experience with the PhysPort website and redesign the website based on those needs, and finally synthesis and fundamental research on effective practices in teaching, learning and assessment.

In the context of our study, we conducted interviews with twenty-three physics instructors from diverse instructional and institutional contexts in the U.S. We seek to capture the "change story" of each physics instructor as they try new ideas in their teaching. Instead of asking about their teaching in general, we ask them how change will occur and what type of motivation and challenges they have.

The target audiences for this study are leaders, designers, developers and anyone else who are seeking to promote the quality of professional development materials and help physics instructors in their growth path.

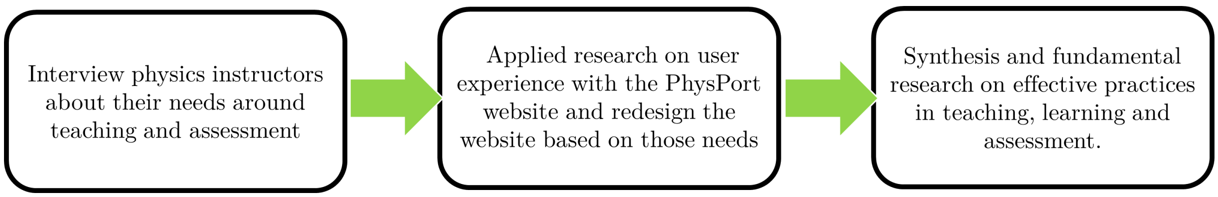


Figure 7.1: *The PhysPort research process.*

7.2 Theoretical approach

Much of this research is quantitative and rooted in resources framework[3;43] and a study by Cohen *et al.*[246]. A cognitive resource, broadly speaking, is a discrete piece of an idea, beliefs or thoughts that a learners (physics instructors) activates when considering to answers the question of "What is it that's going on here in their classroom?"[91–94;103]. More specifically, they are"cognitive elements at various grain sizes that may be in a different state of activation at any given moment"[43].

Hammer, Elby, Scherr, and Redish[103] provide a framework for learning by which learners (instructors) recruit conceptual and epistemological resources, including framing. Instructors have epistemological beliefs that can influence the results of their learning. Epistemological resources usually appears as a cluster of activated cognitive resources. This view of instructors' prior knowledge and epistemological beliefs about learning and teaching, can help us to understand the instructors' current thinking and beliefs towards instructional change. By focusing on instructors as targets of professional development and instructional change, it is very fruitful to interview them. In order to synthesize their needs we need to ask them to describe what are the ways in which they think and talk about applying any changes in their teaching practice?

Despite the importance of identifying instructors' needs and resources in order to improve their teaching practice, we also need to notice how those resources are used by instructors. Cohen *et al.*[246] argue that resources are more extensive than the material resources which often considered such as instructor's knowledge and content materials. In addition, Cohen *et al.* point out the quality of students' outcome depends on the use of those resources in instruction.

Thus, this argument highlights the different ways of instructors' thinking are depend on how the resources are used by them. This broadened study helps us to understand the instructors' prior ideas, knowledge, beliefs, and experiences around implementing new ideas in their teaching.

7.3 Methodology

7.3.1 A methodological approach: Phenomenography

Nowadays, qualitative research is one of a major branches of methodologies. Boeije[247] uses the following statement to define the qualitative research: "The purpose of qualitative research is to describe and understand social phenomena in terms of the meaning people bring to them". This definition reflects my reasoning behind using qualitative research in this study. In this branch of methodology, we attempt to describe the world from the perspective of the people studied and answer the question of why and how of decision making and phenomena experienced. There are several different qualitative research methods, depending on what we are trying to achieve. For example, phenomenography which is sometimes confused with phenomenology is one of them. Both are concerned with individuals' experience and how a phenomenon appears. In phenomenography the purpose is to describe the qualitative variation in people's experience[248–250], whereas phenomenology focuses on investigating and describing a better understanding of the phenomenon itself.

In this study we seek information about the phenomenon of trying new ideas in teaching in real classroom environments from the standpoint of the physics instructors. Thus, we used a phenomenographic analytic method, which can be aimed to discover the variations in instructors' experiences and understanding of various aspects of teaching in the classroom[10;250–257].

Finding a universal definition for phenomenography has been a real challenge, where Marton[10] defined phenomenography as "an empirical research tradition that was designed to answer questions about thinking and learning" and for "mapping the qualitatively different ways in which people experience, conceptualize, perceive, and understand various aspects of, and phenomena in, the world around them". Others have defined phenomenography as "an approach to educational research that appeared in publications in the early 1980s and initially emerged from an empirical rather than theoretical or philosophical basis"[258].

According to Marton and Booth[10;249]:

"Phenomenography is focused on the ways of experiencing different phenomena, ways of seeing them, knowing about them and having skills related to them. The aim is, however, not to find the singular essence, but the variation and the architecture of this variation by different aspects that define the phenomena".

It is important to note that there are not inherently right or wrong ways of experiencing. The main aim of phenomenographic methods is to gain insights into the deeper understanding of instructors' perspective about their teaching. In other words, its point is to discover the qualitatively different ways in which instructors conceive various aspects of their teaching.

Previous literature has argued that different people will not experience the same phenomenon in the same way. However, a phenomenographic approach assumes that there are a limited number of qualitatively different experiences[10]. The phenomenographic research method usually focuses on a small number of participants and assumes the different categories that emerge from them represent of ways that individuals perceive a phenomenon[259].

Data for phenomenographic studies are most typically obtained by recorded semi-structured interviews. The outcome of phenomenographic analysis is a list of categories that describe the qualitative variation of attitudes, beliefs and practices, at the deeper perception of the perspectives of the selected participants (e.g. physics instructors).

7.3.2 Collecting data by interviews

To explore the instructors' perspectives in-depth, the semi-structured interview format was used[10;251;252], which relied on the set of planned questions that revolved around the key beliefs about new ideas they were trying in their teaching. We video-recorded all interviews, with the permission of interviewees.

Prior to conducting an interview, the PhysPort teams considered both the format and the content of the interview protocol D, developing a 45- to 60-minute semi-structured interview protocol to unpack what instructors actually do in the class. The interview consisted of three phases. In the introductory phase, the participants introduce themselves, and talk about their title, previous experience and what courses they are currently teaching. During the next phase of semi-structured interview, participants were asked to describe their new instructional practices: Can you tell me a bit more of an overview of how you're teaching this course? Is there anything new you're trying in your teaching this term? How is this different from how you've taught before? How did you decide to incorporate that into your teaching this term? What's your motivation for trying try this? How do you know if/how well this is working? What have you struggled with in trying to implement new ideas in your teaching? What are some aspects of how you're teaching this course that you are finding challenging? What resources or supports do you draw on to help you with your teaching? What resources or info would you like to have?, and etc.

In the last phase of interview, to wrap up the interview, interviewer asks participants about their gender and ethnicity, and/or any other identities that they have if they are willing to share. Follow up questions are also asked to give participants the opportunity to expand the conceptual meanings of the phrases that they have used during the interview as well as gave them enough room to express their thoughts. The following is an example of a follow up question from our data:

Interviewee: *I just use certain analogies to help them remember; little tricks like that.*

Then ask them questions...

Interviewer: *What do you mean ask them questions? I guess you are talking about...*

7.3.3 Selecting participants for the study

Participants in this study include instructors across various dimensions at U.S. institutions, who have recently made changes to their teaching (big or small) or are planning upcoming changes to their teaching. Participants were recruited through the different sources. We began by sending an email to participants' list of the American Association of Physics Teachers (AAPT) Workshop for New Faculty in Physics. In parallel, some members of our team personally know some instructors who are interested in talking about their teaching. We also sent an email to a listserv of Physics Education Researchers in U.S. asking for their suggestions about instructors who would likely be trying something new and interesting in their teaching during the current semester.

We decided to purposefully sample our interviewees to increase some diversity in our data set, such as gender, years of experience, type of institution, etc. We selected physics instructors, who were in departments called Physics, Physics and Astronomy, or some other grouping of sciences including physics. Overall, different types of instructor participated in this study. For example, Physics instructors who are not necessarily trained in PER, Physics instructors who are relatively new or experienced from a variety of educational institutions, and Physics instructors who are research-stream, teaching-stream, tenure-track, tenured, and adjunct.

Our interviews with physics instructors took place in the Fall of 2018. In the phenomenographic investigation of this study, twenty-three physics instructors were interviewed who had teaching experience on their current institution from zero to forty-seven years. 52% (N=12) had 1-5 years, 14% (N=3) had 6-10 years, 13% (N=3) had 11-15 years, 4% (N=1) had 16-20 years, and 18% (N=4) had more than 21 years of experience. 43% (N=10) of participants taught in private institution and 57% (N=13) participants taught in public institution. Our overall sample was composed of 30% (N=7) women (86% (N=6) white and 14% (N=1) people of color) and 70% (N=16) men (75% (N=12) white and 25% (N=4) people of color).

Across the whole data, we considered various level of institutions, include 9% (N=2) of participants from college with Associates Degree, 18% (N=4) of participants from college with bachelor degree, 30% (N=7) of participants from college with master's degree and 43% (N=10) of participants from college with doctoral degree.

Additionally, confidentiality and anonymity were the top priority. TABLE 7.1 summarizes the participants characteristics, TABLE 7.2, and Appendix C Section C.2 describes each participant's background briefly.

Participants characteristics		**Number**
Gender	Women	7
	Men	16
Ethnicity	Women-white	6
	Women-people of color	1
	Men-white	12
	Men-people of color	4
Years of teaching at current institution	1-5 years	12
	6-10 years	3
	11-15 years	3
	16-20 years	1
	More than 21 years	4
Type of institution	Private	10
	Public	13
Level of institution based on Carnegie classifications	Associate's Colleges: Mixed Transfer/Career and Technical-High Traditional	2
	Baccalaureate Colleges: Arts and Sciences Focus	4
	Master's Colleges and Universities: Larger Programs	7
	Doctoral Universities: Very High Research Activity	10

Table 7.1: *Participants characteristics (N=23)*

Participants	Gender	Years of affiliation	Type of institution
Participant-A	Male	0	Public
Participant-B	Male	47	Private
Participant-C	Male	1	Private
Participant-D	Male	2	Private
Participant-E	Female	34	Public
Participant-F	Male	22	Public
Participant-G	Male	5	Public
Participant-H	Female	11	Public
Participant-I	Male	2	Private
Participant-J	Male	1	Private
Participant-K	Female	3	Public
Participant-L	Female	9	Private
Participant-M	Female	14	Public
Participant-N	Female	10	Public
Participant-O	Male	22	Private
Participant-P	Male	4	Public
Participant-Q	Male	3	Public
Participant-R	Male	5	Public
Participant-S	Male	13	Private
Participant-T	Male	6	Private
Participant-U	Male	0	Public
Participant-V	Male	1	Private
Participant-W	Female	17	Public

Table 7.2: *Participants' background (N=23)*

7.3.4 Data analysis

First, to analyze spoken data, it should be turned into written transcripts[260]. Each of the twenty-three interviews were video recorded and transcribed for analysis by a professional transcription service. After each interview, we wrote down the key points we noticed about the relationship between the interviewee and their teaching. The analysis and coding of interview transcripts were carried out by hand. After a few interviews, we created sets of notes that described each interviewee and each initial categories[261]. The initial categories mostly came from our interview protocol and not only from the instructors' experience.

Later, we got familiar with data and actively engage with the participants, we sought to identify the main category. As categories began to emerge, as a group we updated our interview protocol to probe those categories more carefully in future interviews. After all interviews were completed, the video and transcripts of the interviews became the focus of our phenomenographic analysis.

The collected data were analyzed in order to identify how instructors approach changes in their teaching. I began the data analysis process by reading and carefully re-reading each transcript in order to became familiar with the data and identified a broad initial draft of categories[259;262]. The first draft of categories came from the interview protocol and included other emergent analysis, which came up from the data. For example, an expected initial category came from protocol was motivation behind trying a new teaching idea.

Then I re-read each transcript with a focused of attention on one particular major category and pulled out each quote that is related to the major category. Through this process, I clustered together all quotes that have similar meanings and organized those quotes in a spreadsheet, so that I can look at a particular major category across all interviewees, or I can look at one interviewee across all the major categories[263]. This merging of themes from interviews was done prior to final categories. Each cluster of quotes that had a related aspects of the same thing was grouped into subcategories of descriptions.

Once I have done this for all the quotes, I wrote robust descriptions of each of subcategories. "Definitions of categories are tested against the data, adjusted, retested, and adjusted again" until the descriptions are fixed[263]. Once I have a code book, we coded all the quotes again in that major categories and subcategories. Each main group is called a category (six categories), and each variation within that category is called a subcategory. Figure 7.2 shows the summary of different steps of our phenomenographic analysis to analyze interview transcriptions.

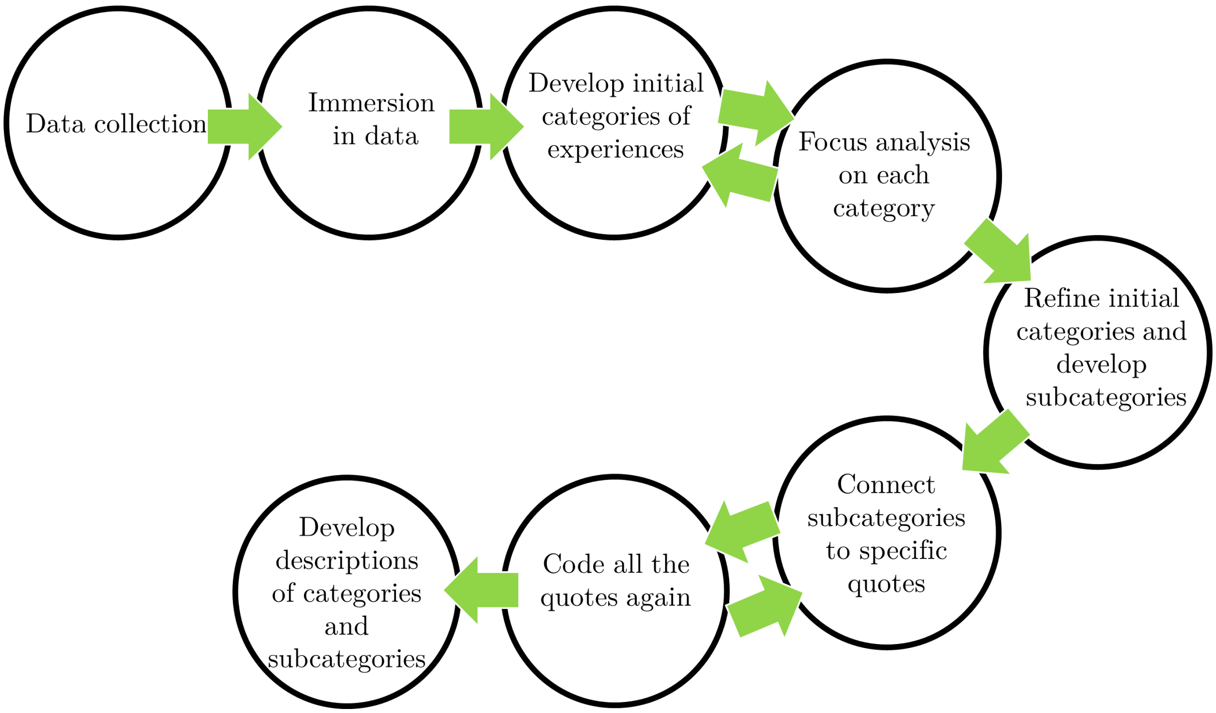


Figure 7.2: *Phenomenographic analysis steps*

7.3.5 Inter-rater reliability (IRR)

We used a phenomenographic approach to analyze each set of interviews separately. A total of 669 quotes were collapsed into six major categories. After several more cycles of analysis and refinement of our data sets, we reached a stable point when our emergent categories were fixed. The major categories were then collapsed into several subcategories. We invited an additional researcher to separately code 10 % of our data set. Before the discussion, 81 % of her coding and mine overlapped. The discussion included explaining and improving parts of the description for each subcategories and discussing each response categorized differently. After the discussion, the IRR, increased to 100 %.

For the second round of inter-rater reliability, we chose the 170 number of written quotes at random for evaluation. The inter-rater reliability over the two pairs of researchers who coded 30 % of the data set, was 83 % before discussion and 99 % after discussion and developed the categories and their descriptions.

We established an average inter-rater reliability of 99.5 % between two independent raters after discussion. We found that the majority of our disagreements were between two major categories: the new practice in instructor's teaching and their motivations for trying something new. To address this issue, we developed the descriptions' of each categories.

7.4 Results: Description of findings

The study is based on a phenomenographic analysis[10] of semi-structured interviews with twenty-three physics instructors, who have recently made changes or they are planning upcoming changes to their teaching.

We analyzed each individual transcript several times. A total of 669 segments of transcript were coded after the interview was analyzed completely. The phenomenographic analysis of physics instructors' responses resulted in several subcategories that we grouped them under six major categories. Following categories might not represent the only possible variations that physics instructors can talk about implementing new ideas in their teaching.

In this section, we provide a rich summaries of the description of six major categories (are shown in bold) and variations within each category (subcategory are shown underlined) that emerged from interviews. In addition, we present some examples of each category and subcategory with segments of transcript to help readers understand the data and its role in supporting our categories of descriptions. Transcript segments are shown in italic.

The findings have implications for a various type of audiences, ranging from PD developers and designers to the institution administrators, and dean of the department. The result is organized around the following six major categories:

1. Goals, motivations and constraints related to applying new changes in their teaching

2. Resources related to new ideas
3. Types of new things that instructors are trying
4. Types of ways that instructors decide a new instructional practice is working
5. Challenges physics instructors experience related to applying new instructional practices
6. Attitudes toward the implementation of new instructional practices

Table 7.3 lists the phenomenographic data analysis findings; the six major categories in bold, the variations within each category (subcategory) and the number of instructors that discussed ideas in each of them.

7.4.1 Goals, motivations and constraints related to applying new changes in their teaching

There are so many factors that encourage instructors to try new ideas in their teaching. However, during the data analysis, we found some common themes across instructors. Instructors needs both intrinsic and extrinsic motivations to create and use some new ideas and resources in their classrooms. These motivations make them take action.

Beneficial for students

All instructors have their own set of reasons for why they teach the way they do. When they described their philosophy of teaching, we noticed that they have different ideas about what is beneficial for their students. Understanding how students learn physics concepts provides an answer to describe why instructor motivate to try new teaching ideas in their classroom. The main feature of this motivation is "it should be beneficial to students".

Some instructors noted that, they want to be a better teacher and build a good relationship with their students (N=10). One of them admitted that he has an ethical obligation as a teacher to seek out the best way to do his job. He added that, *"I think it's a duty to stay* *up to date."* They want their students to have a better experience than they had in their undergraduate level. One junior instructor stated that, *"looking back on my undergrad, I think there were a lot of things that I personally missed out on."*

Some instructors believed (N=9) that, in terms of pedagogy, students need to "practice more" and more. For example quotes included *"traditional labs, didn't help students learn concepts any better"*, *"students learning science process and practices"*, and *"motivating, remembering and practicing are the reasons, why I try to harp on active learning as opposed to me just lecturing in front of them."* For this reason, instructors provide a structural learning environment, both emotionally and physically, so students can achieve their potential. *"So that's when I decided that lecturing really wasn't a very good way to teach because it, just obviously, I was never listening to the students enough to know what problems they were having."* Effective instructors give students the opportunity to interact and promote a discussion among students.

Some interviewed instructors (N=10) noted their interest in getting more of their students involved in a classroom activities. In order to create an engaging learning environment, the instructors need to interact with students, listen to what they're saying and respond to them. One instructor noted that, *"kids are tired, they fall asleep. If you space it right and do activities, that keeps them engaged and awake."* Also, the instructors have to ask questions frequently to make sure students are following along. They engage students and get them to look at issues in a variety of ways. One junior instructor said, *"I like them to be able to work with each other, in front of each other and I like that they get the ability to see different peoples thought process and responses."*

Each student requires different motivational strategies, and instructors need to pay attention to them and their needs to be able to predict what strategies might work. Some instructors believe that providing learning opportunities for students by using any extra technology would be helpful, while others think having a "fun" space and pay more attention to students' needs is important. For example, quotes included *"I ended up looking for things that I thought basically that I thought would be really fun to do"*, *"that was really fun and they were super engaged with that"*, *"lots of useful and fun things in the course"*, and

"It's always been my goal to make learning fun, but at the same time, to make students understand that fun doesn't mean that you don't have to work hard. The fact that I can present something in a funny way may make it actually more memorable and better understood, more nuanced. But that doesn't mean that just because I'm funny, I'm not gonna acquire serious work from students."

Instructors affect/benefit/experiences

The main feature of this motivation is it some instructors are motivated to make changes to their teaching to make it enjoyable appealing and fun for themselves as well as for their students. *"Well, I never knew this could be this much fun, and I won't ever just straight lecture again, because that's not nearly as much fun."* Five instructors believe that teaching is important, and it is supposed to be "fun".

Having a clear teaching philosophy can also motivate instructors to adopt new changes in their teaching. For example, one male instructor mentioned that he used clickers in his lecture courses as a new idea, he tried to get his students to stop and think about what they've just heard and process it in some way and answer a question. He also stated his teaching philosophy as, *"I think as much interaction as possible, as much listening to the students to see what they're actually thinking as possible. I think you can't teach effectively if you don't do that."*

Another instructor stated that, *"I feel like the class is an example of what I want them to be doing. So, I try to set that class up in such a way that I hope that they can pull things out of it, so that when they're teaching that they'll have these memories in their head of what it looked like and how this can be positive.Yeah, so those are the reasons teaching is important to me. I mean if I'm not gonna do it at the very best, if I'm not gonna invest the time and energy to make it really worth- while, then why am I here?"* This motivation may help instructors to provide a better tools for self-evaluation.

Some instructors liked to ask students about their experiences in the course. Getting feedback from students is a very helpful motivation for instructors since they still have the opportunity to make adjustments in the courses. *"I thought it was really nice, because we can get active feedback from the students immediately."*

Observing other people's classes can expose instructors to new methods and resources in action and which can motivate instructors to try them. For example, *"She also introduced me to group exams. I had heard about group exams, but the idea, like how do they even work? Well, she has experience with it, so that first summer she was teaching with us, I was also teaching a summer course and I was totally inspired by her and did group exams. It worked really well in my class."*

In addition to observing other people's class, thinking like a scientist and interacting with other PER people can inspire and motivate them as well. *"The experiences of getting to know the PER committee, which is I was not acquainted with before that when serving on that task force. That really was the most profound influence on this is I came to know these people and came to hear about what it is that they do, and it all made a whole a lot of sense to me."*

Some instructors draw motivation from their personal past experiences. One instructor talked about his past experience of being a Paradigm student and as an English major and a Philosophy major. He learnt a lot through that time. He described, they always sat in a circle and talked and discussed in their classes, and you just discuss, *"it was always interactive and engaging."* He made a hug difference in his teaching based on that experience, when was getting a teacher.

Interestingly, only two instructors talked about research results as a motivator, quotes included, *"showing actual data that lecturing only gets you so much as far as learning gains are concerned."* (instructor with 11 years of experience in current school) and *"I've seen data on it, lecturing can be dead time"* (instructor with 1 years of experience in current school).

Practical considerations and constrains

Having positive and negative motivation is associated with decisions to make changes to the course. Practical considerations can encourage or discourage instructors to make changes.

This subcategory doesn't only represent a motivation around making changes to teaching, but instead mostly describes factors that get in the way of instructors, who are motivated to try new things.

Three instructors felt constrained by their scholarship to try new instructional changes. For example, quotes included *"I did this long after I was tenured"*, *"I'm worried about my scholarship"*, and *"I don't think I'm ever gonna implement them on my own, at least until post-tenure, right? At least until I'm not trying to do other stuff as well and have some freedom to screw up."*

One possible explanation is that, the relative value that their department place one research and teaching may make instructors feel insecure. For example, one instructor noted that, *"I think mostly what I'm struggling with is there is an expectation of teaching excellence and enough support around that that I'm finding myself dedicating 90 % or more of my time towards the teaching."*

Another senior instructor talked about his motivation by keeping the failure rate low. He mentioned that they have weekly meetings with all the instructors, who teach the same course, *"but many of them don't even come"*. He emphasized that, *"teaching is not a major thing here. It's just not what we (the department) value."* Although, he values students-instructor interaction, but he still lectures in his upper-level course, because it's easier and faster to prepare for it.

While most of the interviewed instructors thought their department value teaching more than research, One instructor talked about his strong departmental culture differently. He learned a lot of ideas and specifics of how to implement teaching strategies that he liked and used from NFW. He said, *"like being surrounded colleagues, who value teaching so much, and clearly do the same thing in retention tenured promotion."*

Another example of Practical considerations that can encourage or discourage instructors are environmental conditions, time, and money. Some instructors felt motivated by environmental conditions, such as (e.g., classroom size, planetarium, computer and whiteboards). One of them said *"having the planetarium is inspirational to me in some regards, thinking about how to teach.* In contrast, two other instructors talked about how environmental conditions can constrain the motivation to engage them in instructional change. For example, one junior instructor concerned that he could not use whiteboards in his class, He stated that, *"I want to be able to use those whiteboards, but it doesn't work at all, because the whiteboards are 3-feet by 2-feet and when your desk is 8-inches by 9-inches, those whiteboards aren't a valid option for us."*

In some interviews, instructors referred to the shortage of time. Except one instructor who said, *"feel like I have enough time in the day to really think critically about how I'm developing my course"*, others mostly talked about lack of time and quotes included *"it requires a lot of time that at the moment I don't feel I have"*, *"but, it takes time"*, and *"I don't have enough time to modify the rubric and all the stuff."*

Another point that instructors noted was money, one them said *"I had a lot of money"*, so, he hired people to help him and produce materials for the course. While, other instructor talked about money as a constrain to try something new in his teaching. He stated that, *"If they (students) don't already have it, they have to go buy it, so I didn't want to have that burden on them."* This consideration factors can affect their action and their motivation to try new resources.

Institutional, departmental considerations

Departmental and institutional considerations around motivation to make changes in teaching, include a departmental culture, which values good teaching and serves as a positive motivation to improve teaching. Eight of the interviewed instructors talked about their department is either very encouraging or somehow give them a lot of freedom to improve instruction.

According to our data analysis, it's no surprise that many instructors are in need of institutional motivations as the institution or the administration motivators. They have the ability or power to improve, change, and modify procedures or educational policies to meet the needs of their instructors. When discussing the institutional consideration, we touch on institutional factors that motivate and ask instructors to add a new material to their class to improve student achievement. For example, on instructor said, *"the central office wanted us to go higher up in the U.S. News and Reports ranking, and having a huge lecture course, you know, the student per instructor ratio is too big. So, we could take a huge lecture course and make it small at least in some accounting way, and that will make us look better and then we'll go up in the ranking."*

Other type of extrinsic motivation that makes instructors use, adapt, and implement new resources is departmental expectations. Many departments have strategies and programs designed to meet the learning needs. They require instructors to adapt to new changes or inviting them to propose new changes based on their own considerations. Four instructors mentioned that, their departments wanted to improve teaching and asked them to do more active learning. For instance, one senior instructor who was teaching upper-level courses in past, tried to use some resources from Colorado, University of Washington and Oregon State when he started teaching upper-division Quantum to encourage more active learning in class. He said, *"our department has a lot of emphasis on active learning and in the classroom, which I'm happy to use, but I'm less excited about creating it."* He said, he lectured 75 % of the time, but he tried to do more tutorials in class now. He continued that, *"we (as a department) value good teaching very highly, that it's the most important thing that we do."*

A high level of academic freedom, which motivates instructors to try new ideas and methods as well as tenure requirements which instructors have in the back of their minds when they make changes to their teaching, can positively or negatively motivate them. Institutional considerations include institutional initiatives to improve teaching.

When instructors outlined the support issues that would motivate them to adopt new instructional changes, the most noted one is that administrative encouragement and freedom. Also, some studies indicate that when instructions feel support from their institution, the levels of motivation and dedication are increased[264;265]. For example, quotes included *"there's a ton of support here"*, *"it's a nice environment"*, and *"gave me a lot of freedom."* Although, having freedom and support from the department is "ideal", still intrinsically motivated is needed. When instructors feel freedom to make changes, having an intrinsic motivation can foster their achievements.

Category	Subcategory	Descriptions	Instructor population in theme (N=23)
Goals, motivations and constraint	Beneficial for students	Instructors are motivated to try new teaching ideas in their classroom to help their students learn and understand physics concepts better	20
	Instructors affect benefit and experiences	Instructors need to enjoy and value their teaching as well as for their students	16
	Practical Considerations and Constrains	Instructors have obstacles to get motivated to try new things	13
	Institutional and departmental considerations	Instructors talk about their departmental culture, which values good teaching	9
What resources instructors use related to new ideas?	Online resources	Instructors use online instructional materials which contain a variety of tools	14
	Textbook-related resources	Instructors use supplementary resources associated with textbook materials, lectures notes and materials from other colleagues, research papers, and pre-lecture materials	9
	Books and other materials about how to teach	Instructors use articles and books about methods of teaching and learning in general	9
	Talking to other people	Instructors think talking to other people is a great support resources to learn about new practices	20
How do instructors find resources?	Attending to workshops, conferences, seminars and reading group	Instructors learn about instructional resources by attending to conferences, workshops and seminars to meet other colleagues	17
	Google and twitter	Instructors use search engines such as Google and social media	8
	Individual inspiration	Instructors have been able to get inspired by themselves	3
	Not talking to other people	Some instructors feel not comfortable to talk to other colleagues	4
Resources instructors would like to have	Teaching materials	Instructors like to have more written or online resources that helps them to teach in a better way	13
	Supporting people	Instructors like to have someone that actively gives them comments and feedback on how they can improve their teaching	3

	Kinesthetic activities	Physical body activities resources that make students be physically active in a classroom	2
	Tools	Instructors like to have a particular pedagogical resources such as a whiteboard	1
Types of new instructional practices that instructors are trying	Instructional strategies	Instructors make big changes in their teaching methods in order to engage all students in classroom activities	14
	Content related	Instructors use, create or adopt a new teaching materials	7
	Tools	Instructors use tools such as development tools, online applet, simulations, projector and whiteboards that instructors add them to their teaching materials	13
	Evaluation resources	Instructors examine student learning outcomes, curricular improvement and evaluating instructor's teaching	4
Types of ways that instructors decide something new is working	Benefit Students-based on written evidence	Instructors determine the students' progress about which new ideas will improve their performance, based on written evidence	19
	Benefit students-based on instructor's intuition	Instructors have no written evidence from students, only the sense that they get from the class is determine whether a new instructional changes is working or not	15
	Benefit instructors	Instructors also need to feel the new instructional changes are beneficial for them as well as for students	7
	Benefit Department-institution	Instructors require to make sure that their new teaching approaches will be aligned with the institutional goals	1
	Not working	Some instructors reluctant to talk to people about their teaching	6
Challenges physics instructors experience	Classroom practical consideration	Instructors talk about various range of things, including keeping students quiet in a classroom, providing enough support for all various type of students, implementing new changes and managing their time and covering all the materials	9
	Department cultural consideration	Instructors worry about scholarship, promotion and tenure as a constraint	10
	Engaging students	Instructors want to make students interested in a course	8
	Content materials	Instructors have hard time to deal with the textbook and other materials for their teaching	2
Attitude towards changes	Positive	Instructors are enthusiastic to try new tools and methods	9

	It is hard	Instructors think any changes may be hard at first, but it gets easier after they try it	6
	Changing incrementally	Instructors prefer small, slow steps rather than giant, fast steps	3
	Nervous	Instructors feel nervous and anxious	1

Table 7.3: Descriptions of six major categories (in bold) and associated sub-categories and number of instructors represented by each category.

7.4.2 Resources related to new ideas

Part of this study addresses the following research question:"What instructional resources do physics instructors use?", "How did they learn about new instructional resources?", and "What kind of instructional resources would they like to have?"

- **What type of resources physics instructors use:**

Instructors need a lot of different resources and support to well-manage the learning environment and teach successfully. Instructors require to know about various instructional resources and technologies to help their students to explore ideas relating to different physical concepts, and solve physics problems. Interviewed instructors shared with us three different types of resources they mostly use.

Online resources

The online resources contain a variety of online instructional materials for students and instructors to enhance inquiry-based learning and teaching. It's important for instructors to have access to great online resources to aid their students in working towards a greater understanding of the physics. One senior instructor talked about online portal such as IPLS[266]: *"That's been really helpful. I keep waiting for the IPLS folks to get their website going. I'm looking forward to downloading all sorts of stuff from there and getting new ideas about how to teach more bio-related things. All my students are interested in that."*

Another senior instructor added that *"I do go and search through Physport*[11] *every now and then. Mostly to check up on recent research, or if I hear about somebody who's working on something interesting, and go and look at what other things they've published."* Another instructor liked to *"follow astronomy blogs"*, to get his current information.

Having the opportunity to use various tools, in order to visualize and model various physical concepts, promotes curiosity, exploration, and problem-solving skills in students. Based on interview outcomes, video sharing websites, research-based interactive computer simulations such as PhET[267], blogs, and online environment portal such as IPLS[266] and PhysPort[11] are major resources that interviewed instructors tend to use to encourage and engage students and add a sense of "fun" into their classroom. Overall, sixteen instructors talked about this subcategory across our data.

Textbook-related resources

Instructors can use the supplementary resources to prompt students learning and create an interactive and dynamic classroom environment. Using textbook associated materials, lectures notes, materials from other colleagues, research papers, and pre-lecture materials is all type of resources that instructors can use to share additional information with students. Some instructors, who interviewed for this study believe that using different resources from other colleagues can be useful. For example, one instructor described that this way: *"I was talking to professor that had been teaching this before and gave me some examples on problem sets, exercises that he developed. I mean outside the typical problems that you can find in any textbook like some numerical problems, how to solve them Excel or with MatLab or things like that. So some ideas that he had developed, which I am also implementing."*

Books and other materials about how to teach

Instructors read articles and books about different methods of teaching and learning. It encourages them to remember the reasons why they teach the way they do and keep them updated from other methods. One instructor with six years of teaching experience said: *"I* *go on the American Journal of Physics (AJP) and American Physics teachers website[268]"* to find out what other instructors are doing in their teaching. Teaching methods vary widely, so reading articles and books about it helps instructors to refresh their mind and renew their teaching practices in order to make it their own. Two instructors specifically mentioned about two books that they used to get more idea about how they can enhance and improve their physics class instruction techniques, which is *"Five Easy Lessons[269]: Strategies for Successful Physics Teaching, by Randall Knight"* and the book by Howard Gardner.

Another instructor talked about his new ideas in teaching, which is "Think-Pair-Share" method. He used this methods because, he wanted his students to talk to each other and convince peers about the final answer and voted as a group. *"That I've found to be a lot more effective and that it's leading to better discussions and it's leading to more changes in the votes."* When we asked him about the origin of this idea, he said *"This one might have actually come from AJP (American Journal of Physics). I might have read AJP now no longer publishes physics education research, that was one of the things. But I think I might have read something where they had this idea of consensus building, because I personal goal of mine, and this is something I need to try and do, is for the Physics for the Life Science. I am less concerned about their learning the material and more concerned about thinking scientifically."*

- **How do instructors find resources:**

Since the instructors know best about, their academic need based on their students' background, we asked twenty-three instructors how they find instructional resources in their teaching. Based on our data instructors learn about new instructional resources 10% through googling, 55% through talking to other people, 31% through attending conferences, workshops and seminars and 4% through thinking and inspiring by themselves.

Google and twitter

When instructors want some new instructional materials for their class, they may use search engines such as Google. Google provides tons of links and downloads for instructors to make their lessons more dynamic and beneficial. *"Seeing physics everywhere and examples that I could use to illustrate things for my students, and then I go onto the internet and look for resources like videos and other things that, I can use to illustrate the lectures. I use lots of videos, lots of simulations, all kinds of stuff like that to enhance the content."*

Another thing that one senior instructor mentioned is using twitter, *" I follow some interesting physics people on Twitter. That's been cool. Just seeing what's out there. Especially high school teachers. Again, the high school teachers have some fantastic ideas. It's fun to see what they're doing. I definitely get some ideas from there."*

Individual inspiration

Instructors have been able to get inspired by themselves for coming up class session with new instructional practices. This can help instructors to generate new ideas and think differently about their class. Four of the interviewed instructors talked about their inspiration, one of them said, *"it came to me in a dream. So I'll think, a lot of the time."*. While for other one it happens in a morning before the class: *"I took a shower. You know, I teach at 9:00 AM, I start thinking about class honestly when I get up in the morning like what am I gonna do today. I don't know, that's just it."*

Attending to workshops, conferences, community, seminars, and reading group

Instructors learn about instructional resources in a variety of ways. Conferences is one way that afford instructors the opportunity of meeting other PER and non-PER people across the world and introduce them to new teaching practices. *"I think I would have to say the AAPT conferences would be a big one."* He continued, *"I used to go to both those annual meetings each year and I always get something out of that. There was always people doing interesting things and you could go,"Hey, that's really cool. I can do something along those lines, or I can try that too" I really like those a lot."*

"For institutional support for teaching I'm finding great institutional support. I have been sent to the New Faculty Workshop. I was sent to a, they called it BUFFY, Beyond the First

Year. There's also an AAPT, I guess New Faculty Workshop is AAPT and APS, but the AAPT also does a Beyond the First Year lab thing. I've been sent to that. Very positive experience."

One instructors said, *"I see somebody doing this or I hear somebody doing this if I go to a conference and then I say, "Oh, that sounds neat," and then I'll try it. I'm less of a ... Not even less. I'm not a search it out and read how to do this and then try and incorporate it in my class. I'll sort of go forward and then if I learn something new I will incorporate it, but the learning is not an active search on my part. It's a passive discovery and then, "Oh, can I find out more about that?" But it's usually in a conversation, like can I find out more about how you did that. Or I'll be in a conference in somebody's talking about something and I'll ask more about that. But I don't go to the PER conferences. Where I've done that is more of the advanced lab conferences. I've been to three of those, two of those."*

The teaching center's professional development programs for instructors include workshops, which is a great chance to connect with colleagues from across the institution, delve into the research on learning, and share practical strategies for making their classes more effective. One junior instructor mentioned that, *"That's another place that, I've learned about a lot of these techniques or thought about, had conversations about a lot of these techniques, is various workshops at the Center for Teaching and Learning."*

Another instructor stated that, *"I also think a lot about what students need by having conversations with other instructors who are outside of my department. So, I'm part of a couple of reading groups. One is focused on social justice and institutional change. And, I meet with them every other week. And, we talk about, "What do our science major students need? And, what sorts of experiences do we want students in our college to have around science?" So, that informs a large amount of my teaching."* Reading groups bring together instructors from around the campus, interested in developing their teaching through conversations and introduce them to new resources.

Overall, our analysis reveals that twenty interviewed instructors liked to find resources through attending to different workshops (NFW, CAE, e.g.), seminars, online learning community, TLC, departmental colloquiums, and reading group rather than other ways.

- **Cross-over what-how:**

The following subcategories have cross over between what kind of resources instructors use and how do they find them.

Talking to other people

Another major way that instructors use to learn about instructional resources, is talking to other people. Talking to other people is a great support resources, that can help instructors to learn about other people's ideas. Instructors can easily reach out and connect with their colleagues, TAs, LAs, and Postdocs from different or/and same department or/and institution to get inspired by them and build a more collaborative atmosphere in their institution and community. Here is a list of ways that Interviewed instructors Talked about to communicate with other people:

- Talk to PER and non-PER people
  (at the same/other department/institution)

- Teacher in residence (TIR) program

- Observe other colleague's class at the same/different course

- Conversations with their spouse or partner or anyone out side of the academia

A senior instructor told us that they have *"weekly meetings"* and *"each instructor would have also a meeting of the people who were helping him teach, and that could be up to five people, and his graduate students and his undergraduate students helping him."*

Another instructor shared his experience about talking to the person who was an expert in PER and taught a same course with him. He stated that, *"he taught me, he gave me some good advice about how to talk about the different ways the planets move across the sky at different speeds than starts do, and that sort of stuff."*

The other instructor talked about how the departmental culture helped him to communicate with his other colleagues. He stated that, *"we're running into each other all the* *time and just having casual office conversations about, "Oh, what are you on?" and that sort of thing."* Similarly, another senior instructor, told us *"I mostly just sort of talk to trusted colleagues in the department. I don't venture far outside of the department."*. He detailed that he usually talked about class dynamics, tutorials, reading quizzes and overall class structure. He continued that he feels like the *"physics department is trying to do more and change more rapidly than the other sciences, certainly faster than chemistry. So I end up being pretty insular."*

Interestingly, three interviewed instructors stated that they like to talk to their family members not necessarily just physicists. For instances, one senior female instructor talked about her husband, she stated that, *"he keeps up with stuff so much better than I do and so obviously any time he comes up with something new and he sends it to me then that's fun! looking at general science education things. General things about new research in cognitive science, not really specific to physics education research."*

Another exciting quote that we found in our data, was a bout junior physics instructor that has a fairly good interaction with his pre-tenure colleagues in English department. He detailed how he and another instructor from English department, sat in on each other's classes an discuss. Although, he mentioned he won't implement any of those "cool ideas"- such as write a song about the physics idea or getting up and doing things physically - until get his scholarship, but still he thought, those are *"wonderful ideas"* and he can get more *"interactive in physics classes doing the same type of thing."* In contrast, he also stated that, *"there are three of our very experienced faculty that I talk to a little bit. It's harder. They're my bosses in a sense."* It's not an easy conversation for him. He continued that, one of them is the current chair and the other two may be the next chair, so *"there's a little bit of awkwardness of am I showing weakness."*

- **Resources instructors would like to have:**

Instructional materials and resources are critical ingredients in teaching which help students to follow, understand and implement new knowledge. Instructor would like to access to different types of resources in order to make the learning an exciting and efficient experience.

Teaching materials

As a practical matter, this subcategory means looking for teaching materials and resources; It can be online resources, or sort of written materials such as handbook guide book. For example, one instructor said, *"I would want a website that has really good animations or simulations of difficult concepts like reason why have the seasons, the phases of the moon, all in one website."* While other senior female instructor would like to have a comprehensive handbook guide book. She stated that, *"It would be nice if there were sort of the PER jar, Just some sort of handbook guide book that basically said, here are the important things that you should be doing in a class."* She continued that she is looking for specific advice to be effective and tell her *"you need have to have this characteristic in your classroom. Here is five ways to do that."*

Another junior male instructor felt frustrating about looking for demos on different websites, he stated that, *"I would like to have a nice, big list of inexpensive demos."*

Similarly, another instructor looked for a more practical website, that can provide him something more than Java applets, where he can play with a little sidebar or something and change a variables. *"I've been wanting something a little bit more interactive in terms of essentially like a website that's got a code written in the background where you can actually enter in a bunch of data and have it generate a chart output or something like that. How do you say it? Something that doesn't crash, something that works."* He tried in the past and he couldn't find what he wanted. *"I think that would be something that I would really like, especially for a non-majors class."* One instructor would like to have a repository of questions (e.g., ABCD cards, clickers), *"that are not publicly available."*

Supporting people

Some interviewed instructors (N=5) liked to have someone (in person, via zoom or online discussion) to give them comments and feedback on how they can improve their teaching. They are looking for ways to increase the quality of their teaching materials and their performance. *"You know, if somebody can look through what I have developed, and kind of help* *me bolster it, add content to it, in whatever format it may be. It could be more quizzes, or it could be supplemental video simulations, which will reinforce my lectures."* One instructor talked about the experience that he had with implementing a new idea, he said, it was a *complete failure*. He detailed that it was not working for him, *"I got super nervous, and so I didn't do it again. But, it doesn't mean that that's not a useful method."* He thinks, having a good support from people who may have implemented those methods and seen either success or failure might be helpful, he also would like to have *"some discussion somewhere where people could share ideas and talk about what they did, if it failed. For future [inaudible]"*. He believed that, *"it doesn't matter whether it's success or failure. Knowing that somebody else is doing it, and that it's valuable."*

Kinesthetic activities

One instructor was looking for physical body activities, that not only helps the conceptual ideas in physics, but also engaging students physically. He believed these kinds of activities can help students to participate in the class activity and not get bored. *"There's lots of resources out there that, I have found that are wonderful, like I said, I'm using other resources to help me aid in this construction of the class as I'm doing it now. But that's one thing that I would love to implement that seemed wonderful but seemed to require a lot of activity."*

Tools

One instructor mentioned that, he would like to have some particular/pedagogical resources, such as a whiteboard. Whiteboards allow students to work in groups with other peers collaboratively. He stated that, initially his students looked very shy. They just get the paper and work on the paper. He thought having whiteboards, would provide an opportunity for all students in a class to think and engage with class activities. *"They start to discuss the stuff between themselves. That's why I have that in mind, that probably going back to the whiteboards would be helpful, just to stimulate discussion among them."*

7.4.3 Types of new things that instructors are trying

Teaching is a dynamic occupation. The vast majority of educational improvement efforts involve the implementation of new instructional practices. So, when it comes time to change something in instructors' instructional practices (minor changes or big changes such as change an instructional approach entirely), they rely on different kinds of new resources, to teach in a better way. We found four different kinds of new things that they tried and talked about it during the interviews.

Instructional strategies

Some instructors have specific teaching strategies while others are challenged with determining the best strategy to stimulate student learning. These instructors appear to be the most receptive to adopting new instructional strategies. A number of new different instructional strategies have emerged due to instructors' needs and in order to reveal student thinking. The physics instructors interviewed in this study presented a wide range of teaching strategies examples, such as *"I modify the problem in such a way that even though the student have no idea how to solve it, they would still have something to do in the beginning. And then once they get stuck, then they could talk to the people in their group, and then that could get the ball rolling. So like I guess, everyone have the same problem but I modify my problem in such a way that I think would entice the student to talk."*

Another instructor expressed his philosophy about his teaching to his students. He believed that being clear with his students about his expectations from them, and their role in the class is very important. Sometime when students encounter a new activity, they may be unsure of what is expected of them. *"I don't want my voice to be the dominant voice in the room. I want, you know, this is a time for them to explore the topic in a sort of guided environment, and I see my role as being sort of the person that synthesize all the ideas that people have at the end of each problems."*

Another interviewed instructor mentioned his grading rubric. *"On the very first day, I roll out like basically a rubric for participation grade. So, if they don't show up, there's a* *zero. If they show up and don't say anything, there's a one. If they show up and talk to someone about something about physics within their group or with the whole class, there's two. If they talk twice or more, that's three points. And three is the maximum they could get."* Describing a clear purpose for teaching strategies and expectations may increase students motivation.

Five instructors thought engaging students in drawing, kinesthetic activities and different tweaks can help students to have fun and engage in class activities. One instructor said, *"I made a bunch of different tweaks. I did this goofy thing, which I think has been really fun, where they all sit in rows, and I named all the different rows after the different planets."*

We need to point out that when interviewed instructors were talking about new instructional strategies, they usually talked about making any changes -not necessarily named methods- in teaching that engage all students in classroom activities. For example, pre-activities are a instructional strategy, wherein the instructor present a new activities and exercises to prepare students. One instructor mentioned that his goal is promote students learning about the content, *"I think that is what I'm trying to still develop, is, look how the pre-lab content are so well structured so that the students get better and better understanding of the experiments."* Another instructor pointed to the benefit to his students in engaging somehow. *"I try to have them doing things actually. So, one of the things I've tried to do with varied success is sort of a pre-lecture question style thing, where I'll try to post a few questions kind of building off the reading And then when we get to that topic in class, have students present whatever their answer is and try to spark discussion that way."* Another one talked about, *"try to push them to do some pre-activities before class and then do some other activities in class."*

Twenty-six percent of the interviewed instructors (N=6) mentioned less lecturing and more group discussion as another possible strategy in their classroom. They ask a question or assigns a problem and allows students to think, work, and share ideas with other peers. For example, one junior instructor said, *"I didn't like examples because I am not getting any feedback from them, if that makes sense. So what I've switched to doing, and this takes up the majority of the time, I am not lecturing now, is I will post a problem and I'll have them* *work in small groups and I'll go around."*

Content related

Creating new content (teaching materials) for a real classroom is a big process for most of the instructors and it usually takes time. Some instructors try substantial changes in course content to match the new learning objectives and appeal to students at all levels. For example, three male instructors talked about using a new textbook. *"This year we are teaching from a different book. So, it's the same course but different material actually."*

While the majority of instructors thought that they don't have to totally overhaul their course, they believed that it's a combination of customized content and resources that will allow them to implement small and new instructional practices into their classroom. For example, a junior male participant provided some evidence that he tried conceptual interactive stuff in his teaching in order to keep students engage outside and inside of the class. He stated that, *"a lot of the tutorials tend to be interactive either read and answer questions or conceptual or they have some where you have to match this concept to this definition or something like that. So, anything that was more conceptual, interactive, anything,... that I thought was gonna be a little bit more engaging."* Similarly, some other instructors (N=10) added a little piece of content to the course, such as adding harder problems to their homework, developing a worksheets and using PowerPoint. *"In course content, I added my PowerPoint all the time. I update it, I change examples, I change the homework that I assign."*

A male instructor talked about lab classes in his institution. He detailed that lab was more like a cookbook style and pretty formulaic. Students were doing a worksheet and they were answering very clear questions got a certain number of points. But he did some changes and now, *"there's much less specific guidance, either in the materials that we give them and also in the way that we facilitate their work."* Instructor felt that adding new resources to the class, should bring some benefit to students. He thought that students have to make more decisions now and justify those decisions in order to learn physics.

Tools

Based on our phenomenographic analysis, there are some tools, including development tools (e.g. online applet and simulations) and simple tools (e.g. projector and whiteboards) that physics instructors add them to their teaching materials to create a better learning environments and aid students in their learning process. For example, several instructors thought that the students would have the opportunity to learn and work collaboratively with other peers and their instructor through the whiteboard tool. One male participants with no teaching experience in current institution described that, *"I might try and start them off by just having them go to the white boards or pull up their individual white boards and give them some kind of a prompt to kind of get the class started. And if they're working on the individual white boards it's an individual question, but then they get a chance to go back and forth and see what everybody else does. If it's something where I have them working on the white boards on the walls, I'll split them into groups just kind of counting off randomly and have them answer the questions in groups."*

Additionally, some instructors (N=5) said it's helpful to provide visual aids to support physical concepts. They believed tools designed for providing visual aids, such as PowerPoint, movie clips, and videos can be a very useful tool in physics classroom. One male instructor stated that, *"I've been using some of the movie clips just in classroom too. Watch the movie, we'll watch the clip, and then ask them questions about that. And they seem very engaged."* He found that students seem very engaged but he was not sure that they enjoy. Although, he thought movies are good for conceptual problems, he believed they are not that good for numerical calculations.

Another junior instructor indicated that he used short videos as a weekly course wrap-up, *"basically, it's like a Khan Academy*[270] *style video. I just put together whatever we went through that week."*

Some other instructors described how the MasteringPhysics website[271] improves the dynamics between him and his students. MasteringPhysics website not only allow them to have a feedback from his students' solution, but also help instructors to design some pre-activities base on online tutorials and module in the website. One interviewed instructor noted that, *"I think the biggest thing I have done differently is, I've been trying to use a lot more of the MasteringPhysics, the online components. I've always used it basically for homework because it's not the best feedback but it's immediate feedback and I like that. I've been using it more. I've been relying a lot more on some of the tutorials, the videos, the interactive tutorials."* During the interviews, ten instructors talked about a wide variety of tools that they used newly in their teaching.

Assessment-evaluation resources

The main feature of this subcategory is focused on examining student learning outcomes and curricular improvement. It is an ongoing process aimed at understanding and improving student learning, which range from weekly-minute paper feedback forms to reading quiz. The importance of good feedback allows instructors for many positive opportunities including positive student and instructors relationships. For example, one senior instructor noted that, *"with the pre-session and the pre-class quizzes, the students have a chance to send us feedback every class. Before every class, and we look at that before we go into class. I usually pick some student's comments to respond to. It gets that dialogue going, which is nice."*

Another possible example is when instructors receive feedback from students to increase their effectiveness. Student's feedback can be used to guide instructional revisions. It provides instructors with direct evidence of the results of students' efforts and illustrate precisely the improvements made in students' learning. A pre-tenured instructor admitted that he uses minute-papers, which is a buzzword to have a daily feedback. When we asked the instructor what do you ask on those minute papers forms, he said: *"It's just four questions. This is, what is the main unanswered question, what is the muddiest point? What teaching technique helped you? What teaching technique did not help you?"* In general, five instructors talked about this subcategory across our data.

7.4.4 Types of ways that instructors decide a new instructional practice is working

Many instructors are interested in using new ideas in their instructional practices, but it can be difficult for them to know which changes will work best with their students. Based on the results from our interviews, instructor talked about four different ways which describes how their new teaching practice is working.

Benefit students-based on a written evidence

According to the evidence-based approaches, such as analyzing class data, taking surveys, and using students' written feedback, instructors determine the students' progress and feelings about which new ideas will interest students and improve their performance.

One instructor described that he would like to do exactly the same thing every semester in his class, but that will all depend on how the course goes, he will keep on adding new materials in his teaching. He said, *"from the survey and the grades, how well they learn, how well they think they're learning, I will try to compare with results from previous courses just to see where I'm standing in the overall."* This instructor monitors his own work and self-reflects along the way.

An example of benefit students-based on written evidence would be when an instructor uses exams data to decide if some new instructional change is working effectively or not. *"We had baseline data so we can show, "Okay". This is what we looked like when we were teaching the traditional way, and this what we look like when we teach now."* She thought people found it compelling. Another instructors strove weekly exam to find out what type of change he should keep in his class. *"I'm having an exam this week so I get a little bit more feedback then from what I'm being having with homework and back in class."*

For some instructors, it is more important that their students feel better in general rather than noticing about what is their grades and good feedback. Although, they still get feedback from the students, but think in a broader way about teaching and learning. One senior female participant concerned about her students' feeling. She stated that, *"I get* *feedback that the students appreciate that, and so that's not exactly data that's like, "Yeah, they're learning more," but "they feel better" about the process when they have more time doing that. And that in and of itself, I'm okay with. I think that's kind of a win, that students feel like I hear them, I hear what their needs are, and I'm trying to meet those needs."* She believed for a class full of non-major physics students, who aren't ever going to take physics again, that might be the most important thing that they have a "good feelings" about physics. In contrast, two instructors collected some data - some audio/video filming, IRB, and interviews - so they have all types of data to probe their attitudes.

Benefit students-based on an instructor's intuition

Instructors try to find ways to use innovative teaching ideas in ways that benefit students. Sometimes there is no evidence from students - only the sense that instructors get from the class itself- to determine whether a new instructional change is working well or not. For example, one instructor said *"the sense I got from the class itself was that it was working great. Everybody seemed to get into it on the boards and do a nice job with it in the end."* Similarly, another instructor noted that, *"I walk around the room while they're doing this, and I can hear the misconceptions being reprogrammed by their peers."* This instructor believed that new practices work, because he felt students understand the concepts. *"I don't know. That feels very touchy-feely. I mean, I didn't do any sort of assessment. But, when I did, like the quantum mouse tutorial, I could see the students understanding of like a two-stage system and how to visualize it in Dirac notation and then how to visualize it using a matrix notation."* Another instructor talked about how the essence of the frequently asked questions from the students helped him to evaluate his new practice in teaching, *"and then I go back and decide."*

Based on the results from our interviews, we notice that new instructional changes work perfectly from the instructor's point of view if it helps keep students continuously engaged in class instead of just passively listening. For example, one participant described, *"it worked pretty well. I was very happy how it worked there. That-well was different groups, so it was* *like between 15 and 35 students, and well they really were very engaged in doing the pre-class activities."* This sign helps instructors make a decision about how the new practices work. Listening to students' conversations is an effective way to describe how well the new practices are aligned with the instructor's present teaching practices. *"Walking around the students in a classroom, while they are solving a problem. So, with that I can see how well they are doing or where they're struggling."* Students are doing more interactive and collaborative work in class, including discussions and tasks with their peers and instructor.

One of the participant also wondered, how she start to understand, *"how the students think"* helped her to identify that her new practice was working or not, while she was talking to them in a way that she was not in the lecture.

Based on instructors' intuition, another way to realize how effective is a new practice is looking at students awareness, "are they awake?" or "are they looking at their phone?" One female interviewed instructor said *"they're always sleepy, and then I'll say, "Okay, now a real life story" and then all the sudden they're awake, so I know it works."* In general, fifteen instructors talked about this subcategory across our data.

Benefit instructors

We speak first and foremost about students' benefit. We believe that our students' benefit significantly improves from trying a new instructional methods and a diverse setting. On the other side, instructors also need to feel like the new instructional changes are useful and beneficial for them as well as for students. They have to like it and enjoy it too. This personal benefit can enhance their good attitudes toward the changes. Good time management can be a great sign that new practice is working well for instructors. For example, one instructor said, *"I think it's working really well because we are able to finish everything on time and it just didn't seem to be having a lot of fun. Especially, when they're making presentations, they're really funny."*

One instructors talked about the experiment of conservation of angular momentum that he tried in his class this semester. *"The students started with the masses on the outer stops,* *gave the platform a slow spin, clicked record to measure the angular velocity of the shaft, and then pulled up on the string, pulling the masses in. The shaft would spin up to a higher speed, and then if they lowered the string, the masses would go back out just based upon the dynamics of circular motion. They go back to their outer stops, and the platform would slow down again. By looking at that trace of angular velocity versus time, students could measure the angle of velocity before the masses were pulled in, after the masses were pulled in, calculate the angular momentum."* He said, it was a neat little example that he implemented, and it was neat, *"it works really, really well. I love it."* In general, five instructors talked about this subcategory across our data.

Benefit department and institution

Based on qualitative interviews with physics instructors, they believe that there may be benefits to having an institutional goal. Their fresh ideas must be aligned with the institutional goals to find out how those new instructional ideas work. According to this, it is important that instructors' new teaching approaches are able to provide benefits for their department and institution.

For example, the department notes with some dismay that they are concerned about drop, fail and withdrawal rates. Instructor concerns about student engagement with such options, because the primary reason for a student being in the DFW category, is often lack of willingness to engage with activities or materials. So, instructors try a new teaching practices, resources and strategies to reduce this rate. *"I did a lot of testing over the course of this. If you look in the low, medium, high compared, if you somehow lumped the students into low, medium, high, the percentage gain is the same across those, the low, medium high, so everybody benefits from this. But the ancillary phenomena is the failure rate goes down, but you're talking 5 % of the students. I think it's improved the educational experience for 100 % of the students."* Similarly, another instructor also admitted that *"It worked. Yeah. Although I really don't like to couch in terms of failure rate, I think this has improved everybody's educational experience."* This subcategory includes one male and one female, both instructors from private institution.

7.4.5 Challenges physics instructors experience related to applying new instructional practices

Based on our semi-structured interview, instructors shared with us three different types of challenges they faced with during the implementing new instructional strategies and practices.

Classroom practical consideration

In this subcategory, instructors struggle with a various range of things, including keeping students quiet in a classroom, providing enough support for all various type of students based on their needs, implementing new changes, managing their time, and covering all the materials. This subcategory includes twelve male and seven female: eleven instructors from public institutions and eight instructors from private institutions.

The majority of interviewed instructor talked about time as an issue (N=9 including five male and four female). For example, one senior instructor said, *"the major struggle with that, is not enough time to teach the content that I want to, because I tend to have to cut up stuff, in order to make time for the activities."*

Four instructors particularly talked bout students' diverse background, in term of what physics and mathematics courses they have taken. As an example of a different learning needs of students, one instructor said, *"some of the students haven't taken thermal statistical mechanics yet. Some have. Some haven't taken quantum, some have. So, there's a lot of variation in that, and it's hard."*

One junior male instructor struggled to keep students quite in the class, he said, *"It's hard to keep them quiet. But I have to be a bit more stronger I guess."*

Four instructors found the classroom physical environment is challenging, such as physical space arrangement, adaptation between traditional setting and studio setting. *"The limitation is like the room that get assigned in, because there's so many sections, you can't* *all get like a scale-up classroom. But, I'd done it in both kind of classroom, but it's best when you can move the tables and the chair around."* Similarly, another junior instructor noted that, *"the class, probably the biggest thing I struggle with, is the actual room."* In general, eighteen instructors talked about this subcategory across our data.

Department cultural consideration

Like everyone in academia, instructors also worry about scholarship, promotion, and tenure as a constraint. One male instructor with two years of experience in his current institution noted that the department expect him to teach excellent. *"I think mostly what I'm struggling with is there is an expectation of teaching excellence and enough support around that that I'm finding myself dedicating 90 % or more of my time towards the teaching."* He was worried about my scholarship. He had enough support in his teaching, while much less support on his research work from his department and institution. *"I'm more worried to make sure that I can still publish and that I can make tenure because that's more on my worry. I'm less concerned about the teaching."*

Some instructors mentioned (N=4) that dealing with other colleagues (generally more senior instructors) can be very challenging, and equally frustrating. Those colleagues are more dubious about trying new instructional methods, because they figure, "I already know how to teach." One instructor talked about his experience with the other instructors when he applied some change in the course materials. *"That's when we started breaking up what the material, they had to force them to do interaction. There's still not enough interaction. We still get people who go in and lecture. If it's a tenured faculty member, it's very hard to change that."*

In addition to department cultural challenges, instructors also talked about department limitations, such as the size of the classrooms and lack of classroom equipment. For example, a classroom without computer is hardly a learning environment. *"I've found that that is inhibiting things that I'm able to implement. Like, I also don't have a computer in the classroom."* Another instructor he would *"love trying new stuff"* and make his class *"more* *interactive"*, but he could not be able to do that due to the size of his class. *"Unfortunately my classes are all the wrong size. Too big for the classroom, or much too small. The small ones I don't have a problem because I can work around it since they also involve laboratories, but the big ones are the challenge."* In general, seven instructors talked about this subcategory across our data (five male and two female).

Engaging students

The key challenge found during the interview was making students interested in a subject and get involve in the activity. Some interviewed instructors (N=10) struggled in the classroom and what they can do to engage students. One senior instructor said, *"I think one of the challenges is that when they work together in groups, its hard to tell whether some people are just passive observers."* To prevent students from falling asleep in class or act like a passive observer, the instructors need to do something that can really grab the students' attention. It is essential that students perceive activities as being meaningful and encouraging them to awaken their curiosity and desire to learn. Although, one junior instructor noted that he felt students participate in Classical Advanced Mechanics class, more than in Solid State Physics course, still he believed it's hard for them to get engage in both classes. *"Classical, I always found for most students, because it's every day experiences and that. They're a little more willing to talk and engage in it. But, with this one. Because, everything's so abstract. Like out of the realm of every day experience. Students are really hesitant to engage."*

Another junior instructor talked about how blank stares are the enemy of engagement and learning in his class, *"I like to ask questions and so there's a lot of silence here when I say, okay, let's think about this, and I get up on the board and okay, in this situation what happens? And I just stare at them and I get nothing from this class."* He wondered how he can think about making changes in his practice in order to help students be more responsive during instructional times.

Hence, studying the challenges exist in engaging students, can help instructors in overcoming the obstacles and change their learning moves to become a successful instructor

Hence, more attention needed to increase students' responses and study what other reasons might cause to a lack of engagement and response from students[20;272;273].

Content materials

One of the challenges that instructors is dealing with the textbook and other materials for their teaching including online materials and written homework problem sets. One junior interviewed instructor didn't like the textbook. He believed the textbook *"doesn't spend too much time describing the concepts, and I find it a little bit mathematical and not that physical. So, it focuses into well these are the question and we solve this is and this. But it doesn't spend time talking about what physics is behind all those things.I mean yeah the math is important and you need the math to do solve the question and to solve problems, and you need to know what equations you need to use. But it skips some points that I think it deserves- some of the points that the book skips, I think they deserve a longer explanation or at least just an idea of why that happens, just he starts - at some point just present some equations and say,"Okay that's a question that we need to solve." But it doesn't really explain why and how to get to that equation."* He added that *"I'm not the only one that doesn't like the book but there are other people that really like very much the book."*

It is a difficult and time-consuming task for them to find an interesting and useful online teaching materials to motivated students, who seem to lack any passion for learning and education. One instructors said, that he prefer ask some colleagues, instead of using digital libraries[11;274] to find resources. He stated that *"I find ComPADRE hard to navigate and maybe that's just because I'm an old curmudgeon now, but I don't go to ComPADRE to look for things. So the places where I go to find resources when I'm trying to teach a course is I will basically ask."*

7.4.6 Attitudes toward the implementation of new instructional practices

The key point in this category is how instructors perceive new ideas or practices in their classroom. This category describes instructors' beliefs, behaviors, and feelings during processes of instructional change. By determining instructors' attitudes towards the new instructional practices, we can help them implement a change activity more effectively. Most changes in a physics classroom stem from significant changes in the role of instructor or content materials. Based on our interviewed data, instructor's behavior towards changes in their teaching, may be divided into four personality traits.

Positive

The instructors are positive and enthusiastic about trying new ideas, innovative tools, methods, make some instructional changes in their classroom. Instructors beliefs about change become a natural part of their teaching. One junior instructor said: *"I've always tried to add something every semester to what I'm doing. I've gotten some relatively positive feedback in general. But I try to stay on top of just like adding new components, trying new things out in my courses."*

They are generally confident about their teaching abilities. The majority (N=12) of the physics instructors interviewed in this study described themselves on this subcategory as they are comfortable using new change in their teaching. They convey their passion and enthusiasm for the new changes and their willingness to provide help for students. For example, one of them said: *"I would be open to more suggestions of good activities that people have, because I definitely recognize that my class is not as interactive as it could be."*

In addition, good teaching is important to them. They feel inspired to try new resources in a better way to improve their teaching. This helps instructors to find what they truly want to do with their career path. *"If we aren't going to do it well, why are we doing it at all."*

It's hard [at first but it gets better]

When it comes to creating, adapting, and modifying new teaching methods, it is hard for some instructors to accept this transition abruptly. One instructor talked about it as a *"long process"*, he added that, *"now it works fine. At the beginning we had a lot of start up problems."*

Also, some instructors think they need to spend more time to make any changes. They think it may be hard at first, but it's so worth after they try it, they need to fully understand the complexities involved in their new methods and roles as facilitators rather than transmitters of knowledge. *"When you start something new, it's always harder. But after a while, it might be easier or it might be no extra time, and maybe more rewarding too. Or maybe because it's more regarding, you actually don't mind spending a little extra time."*

Changing incrementally

Instructional change can occur incrementally or suddenly. One senior instructor noted that, *"if you try to change everything at once, you really paint yourself into a corner. That can really cause a lot of personal anguish to the faculty that's taken that upon themselves."*

Most instructors may agree that incremental change over time to achieve good-practice standards requires small-slow steps rather than a giant-fast steps. Another junior instructor said, *"I'll make my PowerPoint slides, I'll pick out problems from the back of the book. I don't like to make drastic changes in the middle, I mean I haven't had that many semesters of teaching. I wanna be fluid, I wanna respond to them. I'll even ask them for feedback at certain points, after exams and whatnot."*

Sometimes instructors making changes over time based on what they could see was working. *"I have a particular way but it's developing. I like to stick with it from semester to semester then kind of incrementally change it, I guess. I am open, somewhat, to making changes. Sometimes I have to hold the line."*

Nervous

Sometimes the instructors backed up that positiveness and enthusiasm with a reason or explanation. The instructional change could be difficult. For example, if the instructional change seems so big and overwhelming, instructors might feel nervous about trying it. This attitude shapes instructors' feelings and perceptions, as well as their behavior concerning change, which usually slows the implementation of educational reform. *"I realized even when I started doing one of these, it's a lot of work and it's a lot of nervousness that goes into it."* Two instructors described their attitude level as nervousness.

7.5 Conclusion

This phenomenographic study aimed to explore the experiences of the instructional change processes, particularly between physics instructors, to help PER community and designers of professional development materials understand their users actual needs. Data was generated from 23 physics instructors interviews. The outcome of the phenomenographic study is a list of emergent categories and the variation within each category (subcategory) are tightly tied to the data. Figure 7.2 briefly describes the process of the phenomenographic analysis.

Regardless of academic background, gender, and type of institution, we identified that all physics instructors had ample great ideas in their teaching practice. However, these ideas are not necessarily framed in terms of implementing a particular PER based-learning material or assessment. For example, one of the junior participants from a public institution talked about PER named methods as a cookbook which is very guided. He continued, *"that's something I don't like."* Only two participants talked about research-based result as a motivation to try new materials in their teaching. Conversely, many participants talked about "fun materials", it should be fun for students as well as fun for instructors. For example, one instructor was looking for *"fun"* and *"compelling"* materials to use in his class that fit well with the textbook he was using.

We asked physics instructors about their motivation for trying new things in their teaching. Some instructors (N=10) noted that they want to be a better teacher and build a good relationship with their students. One admitted that he has an ethical obligation as a teacher to seek out the best way to do his job. Some instructors (N=9) believed that, in terms of pedagogy, students need to practice more and more. For this reason, instructors provide a great structural learning environment, both emotionally and physically, so students can achieve their potential. Effective instructors give students the opportunity to interact and promote a discussion among students. As discussed in Chapter 6, some literature purports the interactions with students place an emphasis on instructors' motivations and has an important factor in making any changes in the classroom[201–203]. Some instructors liked to ask students about their experiences in the course. Getting feedback from students is a very helpful motivation for instructors since they still have the opportunity to make adjustments in the courses.

When we asked physics instructors about "How do you know/decide if the new thing you are trying is working?" many of them mentioned "engagement." We noticed that most of our participants (N=10) value interaction: students need to be engaged, and instructors need to listen to their students. Some instructors talked about their intuition based on the sense that they get from the class itself decided a new instructional change is working well or not. One male instructor said, *"I actually asked students, just in passing, 'Do you guys like this?' And the students were happy about it. Some of them were vocal about it, they were like, 'Yeah, we like this, we want to see more of this stuff.' So that was, you know, I thought that was very bright and positive, for me."*

Another example of how instructors decide if some new instructional change is working effectively or not is based on written evidence such as exam data, teaching evaluations, and written feedback. One instructor said: *"I'm giving a survey on Wednesday to get feedback on how well I'm doing, how well the class is doing, and how well they think they are doing. Just to see if that works for them or if it doesn't work for them."*

When we asked physics instructors about their experiences of trying new things in their teaching, twenty-six percent of the instructors (N=6) talked about less lecturing and more group discussion as possible strategy in their classroom.

When we asked physics instructors about what aspects of teaching they found challenging, three different types of challenges was mentioned: challenges with engaging students, challenges with classroom practical considerations and department cultural consideration, and challenges with content materials. Four instructors particularly talked about students' diverse backgrounds, in terms of what physics and mathematics courses they have taken as a challenges with classroom practical consideration. As an example of the different learning needs of students, one junior male instructor said, *"it's hard to expect them to be all at the same place with the varied backgrounds."*

One male instructor with two years of experience in current private institution noted that the department expects him to teach excellently. All instructors care deeply about good teaching, but articulate practical and institutional constraints. Based on our data, time constraints are big challenge for many participants from public institutions. For example, they feel like they don't have enough time to do all the steps in the inquiry lab and don't have time to cover all the content in lecture. One female instructor from a public institution stated that *"I'm thinking to do something a little bit about the phases of the moon too. I was going to do it this year, but I didn't. I didn't have time. It's always easier just to go with what you've previously done when you're busy."* The findings of this study support the results of previous research indicating that,[185;199] many factors inside the classroom affect instructors' perspectives about applying any changes.

With an ultimate goal of designing resources for PhysPort website[11] to support physics instructors in their teaching, we asked the participants: What type of resources do you use to support your teaching? How do you find those resources? What type of resources would you like to have? The instructors talked about different types of resources that they use in their teaching, including online resources, textbook-related resources, books, materials about how to teach, etc. Instructors learn about new instructional resources through googling, colleagues, conferences, workshops, seminars, and self-inspiration. Many instructors talked about formal and informal interactions as a major way to learn and find resources. One instructor talked about how the departmental culture helped him to communicate with his other colleagues. In addition, instructors would like to access to various types of resources to help students in their learning journey. Some participants mentioned that they would like to have support from a person and a handbook like *"PER in a Jar"*, to introduce them to ideas about active learning and principals of good teaching. Another junior male instructor felt frustrated about looking for demos on different websites. He stated that, *"I would like to have a nice, big list of inexpensive demos."*

As Kwakman[208] suggests, researchers need to pay more attention to instructors cognitive aspects, such as their beliefs and attitudes about implementing new changes in their classroom. Based on our interview data, instructors' behavior towards changes in their teaching may be divided into four personality traits: positive, nervous, It's hard to make any changes but it gets easier after awhile, and changing incrementally. The majority of the physics instructors (N=12) interviewed in this study described their passion and enthusiasm for the new changes and their willingness to provide help for students. Similarly, research has shown the positive effect of PD on instructors' attitudes and beliefs.[150;155–170]. Some instructors think they need to spend more time to make any changes, but many researchers[206;207] argue that change is a process that needs to happen over time. Instructors need to fully understand the complexities involved in their new methods and roles as facilitators rather than transmitters of knowledge. Moreover, the instructional change could be difficult for some instructors and make them nervous. Two instructors described their attitude level as nervousness.

A limitation of this qualitative research study is the sample size of twenty-three physics instructors. Due to the small sample size, the teaching experiences expressed by these participants cannot be used to make broad generalizations of physics instructors.

Overall, the findings of this study are promising for PD designers to develop more useful materials and sustain instructors' performance in the classroom. Being mindful of these points, hopefully the redesign of the PhysPort website with new, more easily usable, material will address some of the instructors needs and concerns.

7.6 Summary

In this chapter, I investigated how physics instructors approach changes in their teaching. The PhysPort team interviewed 23 physics instructors at diverse U.S. institutions about their instructional practices. Our research takes an instructor-centered perspective: what are the ways in which physics instructors think and talk about their teaching practices? I reported a phenomenographic study on physics instructors approach and how it altered their teaching. My phenomenography study explored six different categories: How instructors approach their teaching; their motivation to make changes; resources that they have used; how they have implemented those resources; and challenges they experience during a semester.

Chapter 8

Conclusions and future work

In this dissertation, I have described two central questions about the processes of problem-solving among upper-division physics students and the processes of instructional change among physics instructors.

In Part I, my focus was on students. I discussed three studies in Chapter 2, Chapter 3, and Chapter 4 within KiP theories[1–6] in the service of answering the central question about "how students think about E&M problems". Across all these studies, I found that students' reasoning strategies allow them to know when and how to use their knowledge elements in order to solve a problem productively. I also found that students switch between frames to productively move forward through their solution.

After watching videos of the lectures corresponding to my data in Chapter 2, I found that students usually use resources that instructors put more emphasis on during the lecture. In Chapter 3, I compared students' solutions and the expert-written solutions manual and found that the most repeated resources are common in both. In Chapter 4 I found that the students' frame was affected by other students' framing and as well the instructor's frame. There are many moments in our data that remind us of the role of the expert (including instructors, textbooks, etc.).

As I discussed in Chapter 5, these results raise questions for future investigation around students learning in detail. However, the preliminary analyses suggest an instructor's influence on how students think and understand physics is still very important. The instructor may need to adopt new instructional practices and implement changes as needed to meet the needs of their students.

Instructors have epistemological beliefs that can influence their teaching. An Epistemological resource, is a piece of an idea or beliefs that a physics instructor activates when considering to answers the question of "What is it that's going on here in their classroom?". This view of instructors' prior knowledge and epistemological beliefs about learning and teaching, can help us to understand the instructors' current thinking and beliefs towards instructional change.

In order to understand how instructors are able to help students to construct a better mental models, I implemented a qualitative analysis of the instructors' interviews. In Part II, I have focused on the teaching experiences of instructors in great depth. I asked them to describe the ways in which they think and talk about applying any changes in their teaching practice in order to help their students.

According to the results in Part I, instructors can affect students' thinking. Based on findings in Part II, if instructors want to have a positive influence on how students learn physics concepts, they need to try new instructional practices and implement changes in their classrooms in order to meet the needs of their students.

Both of these parts are founded on an asset-based KiP theoretical view[1–6;275;276]. Asset-based KiP perspective focus on what resources and ideas students and instructors already have rather than, what they don't have. These ideas can be an asset in terms of integrating new knowledge into the knowledge they already have. An asset-based view[275;276] focuses on strengths, supports the idea of diversity in thought as a positive assets, and seeks to build new knowledge from activated different resources[6;103].

The major goal of asset-based practice is to promote and strengthen the factors that support good teaching and learning. An asset-based practice are any ideas or resources which enhances the students' learning, the instructors' good teaching experience, and the PER community's ability to design effective PD materials. In Part I, I valued what resources students bring in problem-solving situation rather than characterized them by what they need to bring. In Part II, regardless of academic or demographic background, I identified that all interviewed instructors valued teaching and had ample great ideas in their teaching practice.

Instructors need to value students' strengths and try to help them to build their knowledge from what is present and useful. In the same way, the PER community and professional development designers need to value instructors ideas and help them deliver more effective instruction to the students and support their teaching. Rather than being characterized good teaching, professional development can emphasize the importance of engaging students and how instructors can provide different pathways for them to success.

These findings are interesting to our field to think about professional development in a new way, such as how physics instructors and PER community can work together to improve student learning. Asset-based perspective enable physics instructors to share their views, values, and their personal teaching experiences with physics education research community. This allow them to be an active factor in the planning, designing and generation of new professional development resources.

We also have found that interviewed instructors are aware of research-based materials, however their motivations and goals that drive them to continue developing their teaching materials and resources is often not what the the PER community and professional developers think and value (such as research-based instructional materials). Too often, professional development focuses on how to teach and how to implement specific teaching methods, not particularly on how students think and learn[165;277]. I have to emphasize that using research-based instructional materials alone are not enough, due to the nature of teaching. Each physics instructor has different educational environments, departmental cultures, challenges, and therefore they need different resources.

The results in Part II indicated that all physics instructors had plenty of wonderful ideas that can help their students' learning. However these ideas are not necessarily framed in terms of implementing a particular named teaching methods or materials. Many instructors described their ideas about teaching with a focus on "engagement" and "fun" activities that assist students in their learning path. Instructors can support student learning by assessing and building knowledge from previous knowledge. All interviewed instructors talked about changes in their teaching. Many of them are motivated to adopt new ideas in order to benefit students' learning.

But, what do physics instructors want in general? How does our field can support them and their students? Based on our data, instructors need support from their department and institution in making any changes in their teaching. Interviewees also talked about their challenges around students' diversity and students' engagement. Many of them shared similar views about "students need to be engaged, and instructors need to listen to their students." Across all the studies, I noticed that there are many expectations and behaviors between instructors and students are common. For example, all interviewed instructors cared about their teaching and students care about their learning. Targeting those physics instructors that are very motivated to help their students should be the main goal of our field. Instructional materials should be designed in order to achieve instructors' goals and students' needs.

Our fields (professional development designers and physics education researchers) need to value instructors' ideas and motivations around teaching, instead of placing emphasis on the implementation of particular PER teaching methods. Thinking is a core component of instructors' professional development, because it is always hard for instructors to implement a new ideas in their teaching that enhance students' thinking skills. Professional development designers are required to design materials to promote thinking skills. This may help instructors - no matter their age, ethnicity, or background - learn to build better teaching practices that are culturally responsive and respectful of students' resources. Since thinking is most often performed in problem-solving situations, instructors can guide students who do not have the required resources and who do not use group settings effectively to understand the concepts more deeply.

There is still much research to be done in fully understanding the physics instructor needs and their views about implementing new ideas in their teaching to assist students learning. There are many avenues of future work deriving from these results. First, further analysis of collected interview data, developing personas, and redesigning the PhysPort website[11;278–280]. We would like to design activities and resources to meet the varied needs of real physics instructors in order to support them through their professional development journey and support their students. To achieve this, we would create a set of personas of our real users. Personas are person-like constructs that are developed based on salient characteristics of actual users[278;281;282]. We would also discuss how these personas can be used more broadly in professional development for physics instructors beyond PhysPort. Developing personas of physics instructors can be used more broadly to improve the design of professional development resources and activities. Designers and developers would use personas to explore who they are designing for and what their actual needs are, instead of just designing for a generic user.

Moreover, post-interviews with some of the participants to study their teaching practices over time would be worthwhile. The data from a longitudinal study may uncover their obstacles and challenges after engaging with asset-based approach with their students. It may also uncover which types of resources have the most effect on their teaching practices and which types need to be improved, in service of supporting and cultivating their teaching of physics. This study is a real opportunity for physics education researchers and those looking to improve learning outcomes.

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Appendix A

Code book

A.1 Chapter 2

Sub-atomic level:

- Nuclei and electrons in reference to each other or within an atom (Internal structure of atoms)
- Distances between positive and negative charges within an atom or within a dipole
- Words such as tension and stretching within an atom

Included as a mention of balancing force:

- Internal force vs. electric force
- Binding strength
- Bond between

Included as a mention of maximum displacement:

- Stretched, polarized, pulled away, separated, and displaced to a certain limit
- Exceeding maximum tension

Included as a mention of breakdown:

- Electron ripped off
- Ionize
- Break down
- Conductor
- Note: Mention of breakdown is counted even if a student discounts it later, because the resource was activated nonetheless.

Super-atomic level:

- Recall an equation
- Mention of atom or dipole without its parts
- Simplified model of charges moving through material instead of electrons moving within an atom
- Properties of material (Susceptibility,...)

Included as a mention of maximum number of atoms:

- There can only be so many poles, dipoles, polarized atoms, aligned atoms
- No more charges available to move
- All dipoles are aligned/polarized

Included as a mention of alignment:

- The dipoles are aligned as the best can be
- Charges, poles, dipoles can't be more aligned

Included as a mention of saturation:

- Draw saturation graph
- Can't get more aligned
- No more atoms left to polarize
- Maximum polarization reached
- Note: Some students mentioned microscopic and macroscopic concepts, and we categorized them as a microscopic.

Appendix B

Transcript

B.1 Chapter 4

B.1.1 First example

15:30-15:36 (6 sec) **Matt:** We are going to try some figure along the y axis and some...

15:36-15:40 (4 sec) **Pause.**

15:40-15:41 (1 sec) **Leo:** I can't draw, like this.

15:41-15:43 (2 sec) **Matt:** I don't know.

15:43-15:48 (5 sec) **Leo:** That looks too weird.

15:48-15:52 (4 sec) **Leo:** We are not going to get anywhere with this guy.

15:52-15:54 (2 sec) **Matt:** We just need a protractor.

15:54-16:05 (9 sec) (Leo uses right hand rule to check the direction.)

16:05-16:12 (7 sec) **Leo:** Okay, so we need $\vec{r}$, $\vec{r'}$ and $\vec{\tau}$.

16:12-16:31 (19 sec) **Pause.** (Leo was writing on the board.)

16:31-16:33 (2 sec) **Matt:** So, $\vec{r'}$?

16:33-16:46 (13 sec) **Pause.**

16:46-16:47 (1 sec) **Matt:** $\vec{\tau}$. (Matt check the whiteboard while Leo was writing the solution.)

16:47-16:55 (8 sec) **Pause.**

16:55-16:57 (2 sec) **Ed:** I am glad to do that.

16:57-17:01 (2 sec) **Leo:** Hey, the triangle.

17:01-17:04 (3 sec) **Pause.**

17:04-17:06 (2 sec) **Matt:** in?

17:06-17:07 (1 sec) **Jacob:** sorry.

17:07-17:09 (2 sec) **Matt:** Is this turn to come in?

17:09-17:11 (2 sec) **Jacob:** this is the thing which due is Monday.

17:11-17:14 (3 sec) **Pause.**

17:14-17:17 (3 sec) **Jacob:** So, all back into

17:17-17:23 (6 sec) **Leo:** express $\vec{\imath}$ in terms of $\vec{r}$ and $\vec{r'}$?

17:23-17:26 (3 sec) **Matt:** $\vec{\imath}$ was equal to $\vec{r'} - \vec{r}$.

17:26-18:41 (15 sec) **Pause.**

18:41-18:46 (5 sec) **Jacob:** I remember part 3 is just like.

18:47-18:50 (3 sec) **Matt:** x', y' time z' minus xyz.

18:50-18:52 (2 sec) **Jacob:** Yeah that is a good way to say it

18:52-18:58 (6 sec) **Matt:** That is how I understood it anyway, so you end up with

18:58-19:00 (sec) **Jacob:** $x' - xy' - y$.

19:00-19:01 (1sec) **Matt:** Yup!

19:01-19:14 (13sec) **Pause.**

19:14-19:16 (2 sec) **Matt:** Is this class 50 minutes also?

19:16-19:17 (1 sec) **Jacob:** Yeah!

19:17-19:20 (3 sec) **Matt:** Okay, do we have any of ...?

19:20-19:22 (2 sec) **Jacob:** Not to my knowledge.

19:22-19:29 (7 sec) **Pause.**

19:29-19:30 (1 sec) **Jacob:** What is the Cartesian components.

19:30-19:34 (4 sec) **Jacob:** $\vec{\imath}$ is in the cylindrical areas.

19:34-19:54 (20 sec) **Pause.**

19:54-20:02 (8 sec) **Jacob:** How is it. What order of the variables in cylindrical.

20:2-20:04 (2 sec) **Leo:** It is r,Φ and z also he used his hand to show z.

20:04-20:06 (2 sec) **Jacob:** Yeah, okay.

20:06-20:17 (11 sec) **Matt:** r,ϕ and z? so then,... (and then he pause)

20:17-20:20 (3 sec) **Jacob:** So, r equals?

20:20-20:22 (2 sec) **Leo:** So, just go to a component again

20:22-20:26 (4 sec) **Jacob:** Yeah, it just want to say r is equal to what ϕ equals and z equals? right?

20:26-20:40 (14 sec) **Leo:** So, for instances r x would be equal to?(and then he paused)

20:40-20:42 (2 sec) **Jacob:** Oh! I see what it says.

20:42-20:51 (9 sec) **Leo:** I think they want us to use S there so, [pause] s is cos.

20:51-20:59 (8 sec) **Pause.**

20:59-21:01 (2 sec) **Matt:** S is going to be cos?

21:01-21:15 (14 sec) **Pause.**

21:15-21:31 (16 sec) **Leo:** That would be a $\cos(\phi)$ and y is $s\sin(\phi)$ and z is just z.

21:31-22:18 (47 sec) **Pause.**

22:18-22:25 (7 sec) **Leo:** It is more spherical coordinates to me because it uses different angle measures whether you are in math department or in a physics department.

22:25-22:56 (31 sec) **Pause.**

22:56-23:05 (9 sec) **Matt:** So it is going to be rsin cos.

23:05- 23:08 (3 sec) **Leo:** oh we are on the 5 now or.

23:08-23:12 (4 sec) **Instructor:** guys, this $\vec{r'}$ belong with the charge or with point p.

23:12-23:18 (6 sec) **Matt:** It's notice prime in the [pause and review his tutorial] coordinate system here...

23:18-23:21 (3 sec) **Instructor:** $\vec{r'}$ goes with the charge? Okay.

23:21-23:25 (4 sec) **Matt:** Oh, it is just a coordinate system SI here denoted x', y', z'.

23:25-23:28 (3 sec) **Instructor:** Ah, Matt just try keep to be consistent.

23:28-23:35 (7 sec) **Instructor:** Oh, excellent que. Good job. $\vec{\imath}$ goes from the charge to point P or from point P to the charge?

23:35-23:40 (5 sec) **Leo:** It goes to the test charge and we know that is positive.

23:40-23:43 (3 sec) **Instructor:** Ah okay. Which of these is a test charges.

23:43-23:45 (2 sec) **Jacob:** The test charge is lower here.

23:45-23:56 (11 sec) **Instructor:** Yeah. You run $\vec{\imath}$ backwards z this may have implications for one part 2 writing $\vec{\imath}$ in terms of $\vec{r}$ and $\vec{r'}$.

23:56-24:00 (4 sec) **Pause.**

24:00-24:02 (2 sec) **Instructor:** Do you want $\vec{r'} - \vec{r}$ or $\vec{r} - \vec{r'}$.

24:02-24:04 (2 sec) **Jacob:** It should be $\vec{r} - \vec{r'}$.

24:04-24:05 (1 sec) **Leo:** Is it?

24:05-24:10 (5 sec) **Jacob:** Because, and then pause.

24:10-24:15 (5 sec) **Matt:** This vector lies this vector what is the wrong direction, right?

24:15-24:21 (7 sec) **Pause.**

24:21-24:27 (6 sec) **Instructor:** Think on this, decide among yourself, and I will come back.

24:27-24:33 (6 sec) **Pause.**

24:33-24:45 (12 sec) **Jacob:** Because, we need a vector to point (use his hand to show the direction) That way and if you (pause)

24:45-24:46 (1 sec) **Matt:** Okay, alright!

24:46-24:51 (5 sec) **Ed:** So, we need to switch all of those to $\vec{r} - \vec{r'}$.

24:51-24:54 (3 sec) **Leo:** That is okay all I have do is write a primes?

24:54-25:25 **Pause.**

25:25-25:30 (5 sec) **Leo:** Now, I am confused again. What is the convention for the direction of these?

25:30-26:18 (4 sec) **Matt:** It makes more, script so it supposed to go $\vec{r'}$ supposed to point to the test charge. When it Got their Cartesian coordinates, this is label this x, y, z prime. In my mind it is better to keep the convention the same then keep the convention she talked, so then if the $\vec{\imath}$ is those from the charge to the test charge the direction is, I am back to the...?

26:28-26:22 (4 sec) **Pause.**

26:22-26:26 (4 sec) **Matt:** Now it makes sense.

26:26-26:28 (2 sec) **Jacob:** What are you saying?

26:28-26:40 (12 sec) **Pause.**

26:40-26:42 (2 sec) **Matt:** Yeah, I don't understand.

26:42-27:10 (28 sec) **Pause.**

27:10-27:20 (10 sec) **Jacob:** You know when you just plotting a stuff on a regular graph, and you got your starting point any point you like to solve the line, you take the end of and it's gonna track with that start with.

27:20-27:24 (4 sec) **Instructor:** You guys figure out this coordinate system business?

27:24-27: 35 (11 sec) **Pause.**

27:35-27:40 (5 sec) **Instructor:** So, $\vec{\imath}$ is $\vec{r} - \vec{r'}$ or $\vec{r'} - \vec{r}$?

27:40-27:44 (4 sec) **Pause.**

27:44-27:47 (3 sec) **Leo:** So, $-\vec{r'}$, because it needs to point in that direction.

27:47-27:55 (8 sec) **Instructor:** And r points mostly on that direction? (Jacob shakes his head.)

Instructor: That is an excellent answer guys. Keep going.

27:55-28:05 (10 sec) **Pause.**

28:05-28:15 (10 sec) **Jacob:** On part 3 we flip around the primes to make $x - x'$ in y' and z', right? But that s all And then part 4 pretty sure it stays the same.

28:15-28:19 (4 sec) **Ed:** That one is just different all together.

38:37-38:39 (2 sec) **Jacob:** So, rx is $r \sin$ yeah?

38:39-38:50 (11 sec) **Matt:** That is what I got. That is 2 components translate to the x y z, translate to x axis.

38:50-39:01 (11 sec) **Matt:** And then you did it again translate to the xy axis, xy pointed there...z one.

39:01-39:06 (5 sec) **Leo:** So, for both they have a $\sin(\theta)$ term.

39:06-39:10 (4 sec) **Matt:** Yes, and then the second term is $\cos(\theta)$ for the x.

39:10-39:13 (3 sec) **Leo:** ϕ.

39:13-39:16 (3 sec) **Matt:** ϕ, yeah

39:16-39:24 (8 sec) **Pause.**

39:24-39:28 (4 sec) **Matt:** And then z is just think it is $\cos(\phi)$, right?

39:28-39:32 (4 sec) **Pause.**

39:32-39:34 (2 sec) **Matt:** You don't need to translate of these.

39:34-39:36 (2 sec) **Pause.**

39:36-39:38 (2 sec) **Jacob:** Yeah, that sounds right.

39:38-40:15 (37 sec) **Pause.**

40:15-40:21 (6 sec) **Leo:** Number 3,... Is cylindrical and spherical coordinates system?

40:21-40:26 (5 sec) **Leo:** By the end of that one it is more, I can't hear.

40:26-40:39 (13 sec) **Pause.**

40:39-40:40 (1 sec) **Instructor:** How is it going guys?

40:40-40:43 (3 sec) **Jacob:** The same physics class for. We feel like we had got the coordinates worked out.

40:43-40:49 (6 sec) **Instructor:** Awesome, good! Are you ready to keep going?

40:49-40:54 (5 sec) **Jacob:** I think so, that is why we are reading the next part and try to decide what to call r.

40:54-41:16 (22 sec) **Instructor:** So, so far you have, let me see that again. Okay. So, you have $r\cos(\theta)$ and $r\sin(\phi)\cos(\phi)$. [Long pause.]

41:16-41:17 (1 sec) **Jacob:** That is not good?

41:17-41:19 (2 sec) **Instructor:** How do you know the rz is that.

41:19-41:23 (4 sec) **Matt:** This is a translation of the z axis.

41:23-41:24 (1 sec) **Instructor:** Okay!

41:24-41:31 (7 sec) **Matt:** So, we gave it θ and,... particular triangle.

41:31-41:34 (3 sec) **Instructor:** Okay, how come there is no ϕ in that.

41:34-41:37 (3 sec) **Leo:** It is up to the translated to the xy ha.

41:37-41:39 (2 sec) **Matt:** It is not dependent on ϕ.

41:39-41:46 (7 sec) **Instructor:** No matter what ϕ is, it would be the same? Okay good.

41:46-41:47 (1 sec) **Jacob:** So, we are good?

41:47-41:48 (1 sec) **Instructor:** Yeah!

41:48-42:05 (7 sec) **Pause.**

42:05-42:08 (3 sec) **Jacob:** Before we used xyz for the point of interest, right?

42:08-42:16 (8 sec) **Jacob:** So, I am gonna keep that consistent, and call this I try to record the position xyz.

42:16-42:32 (16 sec) **Matt:** Back to her, notation is has meaning that the x' and y' coordinate is at a tri? coordinate.

42:32-42:34 (2 sec) **Jacob:** At the earlier.

42:34-42:40 (7 sec) **Matt:** At the earlier right I am not agree with this, earlier one has to flipped but then,...hard time.

42:40-42:43 (3 sec) **Jacob:** So, is that. We have error along the wrong way though?

42:43-42:51 (8 sec) **Matt:** She mentioned that the prime coordinates where at the test charge.

42:51-42:53 (2 sec) **Jacob:** Oh, okay.

42:53-43:00 (7 sec) **Matt:** So, when we flipped it. Look at that.

43:00-43:06 (6 sec) **Leo:** We don't need to worry about prime so much in this one since we got the ring and not a single point at this one.

43:06-43:10 (4 sec) **Jacob:** Yeah but it wont see the label xyz, $x'y'z'$.

43:10-43:13 (3 sec) **Matt:** Yeah! that asks you to label the point on the plane.

43:13-43:14 (1 sec) **Leo:** Okay.

43:14-43:25 (11 sec) **Matt:** I just arbitrary -x,y,z just I need a ring or- [inaudible].

43:25-43:34 (9 sec) **Pause.**

43:34-43:52 (18 sec) **Matt:** You know what he has, Griffiths has the prime.

43:52-43:54 (2 sec) **Leo:** For now, let's just big r and stay consistent.

43:54-43:58 (4 sec) **Matt:** $\vec{r} - \vec{r'}$, he doesn't the way that we are here.

43:58-44:06 (8 sec) **Jacob:** So, supposed if, just make me confused.

44:06-44:11 (5 sec) **Matt:** Let's be consistent, all we are doing prime on the tri quarter

44:11-44:12 (1 sec) **Leo:** Sure!

44:12-44:19 (7 sec) **Matt:** So, he does.

44:19-44:31 (12 sec) **Jacob:** so regular $\vec{r}$ should be pointing to the premature an $\vec{r'}$ should be pointing to the tri-quarter and then the $\vec{\imath}$ is should be the plane of the tire to the tri-quarter.

44:31-44:49 (18 sec) **Matt:** yes, and now Griffiths does it the way on his front page, $\vec{r'}$ points to the charge and $\vec{r}$ points to the ...

So, you want to stay consistent or switch

44:49-44:51 (2 sec) **Leo:** We already pick, let's go

44:51-45:17 (26 sec) **Unrelated talk.**

45:17-45:21 (4 sec) **Jacob:**: I write down the formal integral expression for the electric field, ready to specify.

45:21-45:34 (13 sec) **Matt:** So, just be a line charge in cylindrical.

45:34-45:40 (6 sec) **Leo:** Yeah, this time we are its, our bounds are angles zero to 2π right?

45:40-45: 45 (5 sec) **Matt:** Is cylindrical is spherical? Does it matter is it?

45:45-45:47 (2 sec) **Leo:** This one is,...

45:47-45:51 (4 sec) **Matt:** Cylindrical, z easiest.

45:51-45:57 (6 sec) **Leo:** I can't hear talk about tri-quarter offset.

45:57-46:01 (4 sec) **Jacob:** Where exactly the tri-quarter supposed to be?

46:01-46:05 (4 sec) **Matt:** It sr he just writes here (Matt checked his notes)

46:05-46:20 (15 sec) **Jacob:** I mean, I'm giving this we could figure out sphere I'm pretty sure, neither stay in ϕ.

46:20-46:27 (7 sec) **Matt:** It is arbitrary. (He keep reviewing textbook)

46:27-46:30 (3 sec) **Jacob:** I think cylindrical seems pretty good.

46:30-46:46 (16 sec) **Matt:** I am disagree with because, it is off center. But, I care too much, let's stop talking about this and pick cylindrical.

46:46-46:51 (5 sec) **Leo:** We can try the cylindrical, if we figure it out that doesn't work, we can always switch.

46:51-47:05 (14 sec) **Matt:** So, the general form is on textbook the general form for the line charge it s gonna be a k integral charge out of... bda.

47:05-47:33 (28 sec) **Leo:** We have let see the charge is gonna be that lamtime $2\pi r$.

47:33-47:38 (5 sec) **Pause.**

47:38-47:39 (1 sec) **Jacob:** λ?

47:39-47:43 (4 sec) **Matt:** λr, but it is gonna be constant. I assume does it say constant.

47:43-47:49 (6 sec) **Pause.**

47:49-47:50 (1 sec) **Ed:** λ is constant?

47:50-47:51 (1 sec) **Matt:** Yeah!

47:51-47:57 (6 sec) **Pause.**

47:57.48:10 (13 sec) **Matt:** That is the general form, so we have to turn that into this would be Cartesian coordinates.

48:10-48:23 (13 sec) **Leo:** So, if we are taking the cylindrical we just need to add to make this one work out we need to turn that$2\pi r$.

48:23-48:31 (8 sec) **Jacob:** Regardless. That is the charge amount is the that we are looking at, right?

48:31-48:33 (2 sec) **Matt:** Times the, one?

48:33-48:35 (2 sec) **Leo:** $2\pi r$.

48:35-48:56 (21 sec) **Jacob:** Wait hang on we are guessing the integral, the integral is a little tiny piece of charge and not the all the charges once, yeah the 2π is taking care of the bounce.

48:56-48:58 (2 sec) **Leo:** Yeah, right.

B.1.2 Second example

2:07-2:13 (6 sec) **Leo:** So, we don't know still number 3 on the other one? Right?

2:13-2:20 (7 sec) **Jacob:** I am pretty sure that 3 goes down to E is equal to big $R\sigma$ over $\epsilon_0 r$.

2:20-2:23 (3 sec) **Leo:** Yeah, that is what I got.

2:23-2:27 (4 sec) **Pause.**

2:27-2:28 (1 sec) **Leo:** And the number 4 is easy.

2:28-2:34 (6 sec) **Leo:** There is not an affect on the everything on the inside but everything on the outside is in danger of electric fusuin.

2:34-2:36 (2 sec) **Ed:** Depending on how big is σ is.

2:36-2:38 (2 sec) **Matt:** We never did solve this.

2:38-2:40 (2 sec) **Leo:** Well, so it was a lighting straight so, Pause.

2:40-2:42 (2 sec) **Leo:** The beam line was cylinder. Right? So?

2:42-2:44 (2 sec) **Leo:** I was hope it is differently. [inaudible]

2:44-2:49 (5 sec) **Instructor:** So there is a beam line itself and there is a cylinder that contains it.

2:49-2:55 (6 sec) **Jacob:** Oh Okay. The beam line is the actual electrons, that we are looking at.

2:55-2:57 (2 sec) **Instructor:** Line of beams.

2:57-3:01 (4 sec) **Matt:** It says the charge on the beam line affected the beam particles, causing them.

3:01-3:06 (5 sec) **Instructor:** Well, I take it back, that means the charge on the cylinder affect with the particle that composed the beam.

3:06-3:07 (1 sec) **Matt:** Okay!

3:07-3:09 (2 sec) **Jacob:** Okay!

3:09-3:11 (2 sec) **Matt:** So, it is no and yes?

3:11-3:14 (3 sec) **Instructor:** So, the answer is yes or the answer is no?

3:14-3:15 (1 sec) **Matt:** No and yes.

3:15-3:16 (1 sec) **Instructor:** It cant be both.

3:16-3:17 (1 sec) **Ed:** No for the first part and yes for the second part.

3:17-3:18 (1 sec) **Matt:** No, yes!

3:18-3:19 (1 sec) **Instructor:** Exactly! yes!

3:19-3:46 (27 sec) **Unrelated talk.**

3:46-3:49 (3 sec) **Jacob:** Would you like to borrow a pen? It s a nice pen.

3:49-3:50 (1 sec) **Leo:** Eh, but it is a pen.

3:50-3:56 (6 sec) **Jacob:** Are you too good for pens?

3:56-4:08 (12 sec) **Jacob:** Make mistake you can correct it.

4:08-4:10 (2 sec) **Instructor:** How is everything keep going guys?

4:10-4:12 (2 sec) **Leo:** We are not with sharpest pencil.

4:12-4:16 (4 sec) **Jacob:** I am wonder, how to say that symmetry will cancel things now?

4:16-4:39 (23 sec) **Instructor:** You can always say that, but if I ask you what is that mean, you should be able to explain how it is that you mean symmetry. So yes, you totally can say , Oh yeah by symmetry, it is all equal to zero. But if I ask you like tell me a little bit more bout how symmetry let you say that. You should be able to explain yourself.

4.39-4.40 (1 sec) **Jacob:** Okay!

4.40-4.41 (1 sec) **Instructor:** Good.

4:41-5:09 (18 sec) **Unrelated talk.**

5:09-5:11 (2 sec) **Instructor:** None of that is a bout Gauss's law.

5:11-5:12 (1 sec) **Jacob:** No it is not.

5:12-5:15 (3 sec) **Instructor:** Okay, continue with the Gauss's law.

5:15-5:17 (2 sec) **Leo:** So?

5:19- 5:21 (2 sec) **Leo:** Started on the homework side I guess.

5:21-5:30 (9 sec) **Matt:** He-he, good call, because I didn't turn that in.

5:30-5:34 (4 sec) **Ed:** So, she is not grading that part.

5:34-5:40 (6 sec) **Pause.**

5:40-5:50 (10 sec) **Leo:** So, since it once a delta function for number one on number 3, but I didn't use a delta function.

5:50-6:00 (10 sec) **Matt:** What? We use delta function in number 1? where did we use that?

6:00-6:02 (2 sec) **Leo:** Okay, I started on that way.

6:02-6:05 (3 sec) **Leo:** Because, I had some free time in the library.

6:05-6:07 (2 sec) **Jacob to Leo:** Oh, hang on, what were you saying?

6:07-6:20 (13 sec) **Leo:** This one I did without a delta function but number 3 asks for the units of the delta function in number 1. But I didn't use a delta function.

6:20-6:25 (5 sec) **Pause.**

6:25-6:27 (2 sec) **Matt:** How would you collapse that?

6:27-6:34 (7 sec) **Leo:** Well, we still talking about the charge on the cylinder. Right?

6:34-6:41 (7 sec) **Jacob:** I think you were restricted to the radius of the cylinder.

6:41-6:55 (14 sec) **Leo:** Yeah. You squeezed To the radius. But you got r and the delta , delta term which it turn out just to be r.

6:55-6:57 (2 sec) **Jacob:** Right! When you integrated it.

6:57-7:04 (7 sec) **Pause.**

7:04- 7:10 (6 sec) **Matt:** So, we should assume that it is just linear acceleration not a cylindrical.

7:10-7:13 (3 sec) **Jacob:** Pretty sure.[inaudible]

7:13-7:16 (3 sec) **Pause.**

7:16-7:17 (1 sec) **Matt:** So, then?

7:16-7:20 (4 sec) **Pause.**

7:20-7:30 (10 sec) **Leo:** I just did diametrically and $\frac{2\pi r L\sigma}{\pi r^2 L}$.

7:30-7:38 (8 sec) **Pause.**

7:38-7:41 (3 sec) **Jacob:** Maybe, for... are you coming up with a numeric answer?

7:41-7:43 (2 sec) **Leo:** What?

7:43-7:46 (3 sec) **Jacob:** Is that numeric answer that I have seen?

7:46-7:47 (1 sec) **Matt:** He actually did.

7:47-7:50 (3 sec) **Leo:** It is $\frac{2\sigma}{2.6}$ meters.

7:50-7:54 (4 sec) **Matt:** Oh, cylindrical coordinates, never mind, I am sorry.

7:54-8:02 (8 sec) **Leo:** Which works out to the right units,it is correct geometrically.

8:02-8:04 (2 sec) **Jacob:** Right.

8:04-8:07 (3 sec) **Leo:** I don't know what she means by purely mathematical.

8:07-8:26 (19 sec) **Pause.**

8:26-8:34 (8 sec) **Jacob:** Yes, it is supposed to be a delta function because part two asked you to integrated, so definitely it has to be delta in somewhere.

8:34-8:40 (6 sec) **Matt:** Beyond among squeeze,[inaudible] talks about result.

8:40-8:43 (3 sec) **Matt:** but, ...

8:43-8:49 (6 sec) **Leo:** But you get an r terms in there as well. Don't you? So it just turns into r.

8:49-8:55 (6 sec) **Matt:** Well no integrating that over infinity...gives you 1.

8:55-9:02 (7 sec) **Leo:** Yes but you have to r multiply by that so it is evaluated just by r.

9:02-9:05 (3 sec) **Pause.**

9:05-9:07 (2 sec) **Matt:** Pretty sure it should.

9:07-9:12 (5 sec) **Pause.**

9:12-9:18 (6 sec) **Jacob:** You just set up like here is (long Pause.)

9:18-9:23 (5 sec) **Pause.**

9:23-9:29 (6 sec) **Leo:** It supposed when you set up a delta function you have delta r.

9:29-9:34 (5 sec) **Jacob:** Hang on, hang on.

9:34-9:37 (3 sec) **Jacob:** We still doing like a surface charge. Right?

9:37-9:40 (3 sec) **Leo:** Well that is the only charge there.

9:40-9:43 (3 sec) **Jacob:** But, it wants a volume charge density.

9:43-9:48 (5 sec) **Leo:** Yes, but a volume charge density is what? The total charge of the volume. Right?

9:48-9:53 (5 sec) **Leo:** Is the surface charge multiply by the surface area, divided by the volume.

9:53-9:55 (2 sec) **Jacob:** Good.

9:55-9:56 (1 sec) **Matt:** There is no volume.

9:56-10:00 (4 sec) **Leo:** There is a volume. The volume is the volume of the cylinder.

10:00-10:03 (3 sec) **Jacob:** But it is an open cylinder, I am pretty sure.

10:03-10:06 (3 sec) **Matt:** It is an infinitely thinned walled cylinder.

10:06-10:08 (2 sec) **Jacob:** I think it is what it is.

10:08-10:10 (2 sec) **Matt:** It is a shell.

10:10-10:12 (2 sec) **Jacob:** It cant be right.

10:12-10:15 (3 sec) **Leo:** We want to point on volume of the shell?

10:15-10:20 (5 sec) **Matt:** Well, the volume charge is something there is no volume to this.

10:20-10:21 (1 sec) **Jacob:** Maybe it is (Pause.)

10:21-10:23 (2 sec) **Matt:** Volume charge of the surface.

10:23-10:25 (2 sec) **Jacob:** Yeah what the heck.

10:25-10:39 (14 sec) **Leo:** Well, I guess if that s where we are going for the delta function might make sense. I was thinking the entire cylinder volume. I guess, it doesn't work like that.

10:39-10:45 (6 sec) **Matt:** It doesn't there is no thickness. Unless you just say something entire wrong.

10:45-10:51 (6 sec) **Pause.**

10:51-10:53 (2 sec) (Leo erased his solution) **Jacob:** You don't necessarily to erase that.

10:53-10:57 (4 sec) **Leo:** Well if we are not actually using volume of the cylinder.

10:57-11:02 (5 sec) **Jacob:** Yeah, that is the thing I wanna find out, because I am like super confused right now about,...[inaudible]

11:02-11:05 (3 sec) **Leo:** Okay, if we are, I can just go back to it that s simple, but...

11:05-11:11 (6 sec) **Pause.**

11:11- 11:13 (2 sec) **Leo:** (with a question tone) Volume of the shell?

11:13-11:14 (1 sec) **Jacob:** Right.

11:14-11:17 (3 sec) **Leo:** It is like the sounds of one hand clapping.

11:17-11:21 (4 sec) **Jacob:** 2 hands clapping. [Laughing]

11:21-11:26 (5 sec) [Laughing]

11:26- 11:36 (40 sec) **Jacob:** So, I feel like it is supposed to be if the still there have caps on it.

11:36-11:38 (2 sec) **Leo:** Whats the volume?

11:38-11:41 (3 sec) **Leo:** Then you don't need a delta function.

Jacob: right!

11:41-11:54 (13 sec) **Matt:** So, we should go here, total charge, you got *deltaz* , one z.

11:54-11:56 (2 sec) **Matt:** You don't want a *deltaz* term?

11:56-11:58 (2 sec) **Matt:** That s fine, just try it to think it very well.

11:58-12:05 (7 sec) **Jacob:** Yeah this is for y, that s why she squeezed it to the z axis.

12:05-12:06 (1 sec) **Instructor:** What is going on guys?

12:06-12:13 (7 sec) **Matt:** Problem one asks for volume charge density but the surface has no volume. What?

12:13-12:15 (2 sec) **Instructor:** I will use a delta function.

12:15-12:17 (2 sec) **Jacob:** Okay.

12:17-12:26 (9 sec) **Leo:** Okay. So, we are finding the volume density for entire cylinder or just for in shell?

12:26-12:28 (2 sec) **Instructor:** The shell.

12:28-12:29 (1 sec) **Leo:** Okay!

12:29-12:33 (4 sec) **Jacob:** What is the mean of have a volume charge on a surface though?

12:33-12:38 (5 sec) **Instructor:** Did it bother you earlier when we talked about point charge on the line?

12:38-12:43 (5 sec) **Jacob:** I don't remember exactly what is the point charge on line.

12:43-12:46 (3 sec) **Instructor:** We used a form of delta function.

12:46-12:58 (12 sec) **Matt:** Yeah I see. She's got a (Pause). we used a a volume density or volume charge density for the 2 points problem.

12:58-13:02 (4 sec) **Leo:** Okay.

13:02-13:09 (7 sec) **Matt:** We just collapse it in one dimension. Not all the dimension.

13:09-13:18 (9 sec) **Instructor:** So, delta function is squeezing function. So we have all the space we will squeeze it in to the infinitely thin part in one dimension.

13:18-13:20 (2 sec) **Leo:** In this case we are just squeeze it to the radius. Right?

13:20-13:21 (1 sec) **Jacob:** Yeah.

13:21-13:22 (1 sec) **Instructor:** All right.

13:22-13:38 (16 sec) **Matt:** Wait does units work? Because if we have z we have r. means z is meters. meters squared because that is gonna fall out.

13:38-13:39 (1 sec) **Jacob:** Yeah!

13:39-13:44 (5 sec) **Leo:** The only difference from that is this time we are using a σ instead of λ. Right?

13:44-13:56 (12 sec) **Matt:** Right. Because, when we integrated r squared we use [inaudible]. I don't understand that why that r just pulls out r squared.

13:56-14:00 (4 sec) **Leo:** *Delta* r minus d, I guess.

14:00-14:02 (2 sec) **Matt:** Oh, okay! I am sorry.

14:02-14:09 (7 sec) **Leo:** The first term is *deltar* minus *d* means the radius of the shell.

14:09-14:13 (4 sec) **Jacob:** It will the integrated with this, right?

14:13-14:19 (6 sec) **Leo:** Something like that I don't know yet, I don't finish it. But...

14:19-14:26 (7 sec) **Pause.**

14:26-14:33 (7 sec) **Jacob:** So, that squeeze the radius of the cylinder, right?

14:33-14:34 (1 sec) **Leo:** Ihum.

14:34.14:42 (8 sec) **Jacob:** And then it can be anywhere on the z axis and as many pi as you like, right?

14:42-14:45 (3 sec) **Leo:** 0 to 2π would make sense, but...

14:45-15:06 (21 sec) **Jacob:** Yeah you can have half π though. and then you just have a *rdzd* term, right?

15:06-15:13 (7 sec) **Pause.**

15:13-15:14 (1 sec) **Jacob:** So, it needs to be a triple integral? Right?

15:14-15:15 (1 sec) **Leo:** Yes.

15:15-15:20 (5 sec) **Pause.**

15:20-15:22 (2 sec) **Jacob:** Oh, we have to have a charge somewhere.

15:22-15:25 (3 sec) **Leo:** So, this is gonna be,...(Pause)

15:25-15:31 (6 sec) **Matt:** We also looking for a density right? Not all the charge.

15:31-15:37 (6 sec) **Jacob:** Yeah. So I think we start with the q on this side.and then we ended up with you know, we have a on the other side. And we have to flip it around.

15:37-15:43 (6 sec) **Pause.**

15:43-16:08 (25 sec) **Leo:** But, we can do that right? Start with q equals triple integral *deltar* minus *d* and then we have got d something, and we have got a on there and we have got *dzd*.

16:08-16:10 (2 sec) **Jacob:** We need *r*, *rdzd*.

16:10-16:13 (3 sec) **Jacob:** Or that is what the delta function is. Is not it?

16:13-16:15 (2 sec) **Jacob:** I don't think so.

16:15-16:23 (8 sec) **Matt:** So, she is writing *rdzdrd*.

16:23-16:24 (1 sec) **Jacob:** This is for the ring?

16:24-16:25 (1 sec) **Matt:** This is for (Pause.) the volume.

16:25-16:30 (5 sec) **Leo:** All right, we don't need r we need r squared term if it is a volume. Don't we?

16:30-16:37 (7 sec) **Pause.**

16:37-16:39 (2 sec) **Matt:** What is the book says.

16:39-16:43 (4 sec) **Leo:** Looking at the textbook?

16:43-17:14 (31 sec) **Pause.** (All groups members were looking at the textbook.)

17:14-17:20 (6 sec) **Jacob:** We just try to figure it out what we are supposed to do for cylindrical coordinates. Right?

17:20-17:28 (8 sec) **Leo:** Well, specifically what term we need as far as r goes to make this A volume integral.

17:28-17:41 (13 sec) **Jacob:** All right, so we have got cylindrical. it just said cylindrical dl and d and this is in front of the book.

17:41-17:47 (6 sec) **Leo:** Try looking in the Dirac function section which starts on page 45.

17:47-17:59 (12 sec) **Jacob:** Okay, yeah, but we are looking for what to do about the cylindrical coordinate and not what to do about delta function. we are cool with the delta function part right?

17:59-18:02 (3 sec) **Leo:** What are we confused about cylindrical coordinates?

18:02-18:05 (3 sec) **Jacob:** Just what needs to come after a delta function part basically. Right?

18:05-18:17 (12 sec) **Leo:** Well, it is a volume so we need $dzddr$. Right?

18:17-18:19 (2 sec) **Pause.**

18:19-18:23 (4 sec) **Jacob:** I am pretty sure there is a extra terms of r in there.

18:23-18:28 (5 sec) **Leo:** Yeah, that s just I am trying to figure it out , it is r or r squared or something else.

18:28-18:32 (4 sec) **Jacob:** I think it is just an r, I cant say for sure.

18:32- 18:37 (5 sec) **Pause.**

18:37-18:45 (28 sec) **Jacob:** Oh, okay. Yeah , what the book is saying is the like, oh yeah I remember her talking about d

18:45-19:05 (20 sec) **Jacob:** So, in front here there is a Cartesian coordinates for a length you've got this chunk and end with $dxdydz$ and For spherical coordinates the stuff we attacked is r squared sin theta dr d theta d and then for cylindrical coordinates is attack at the end is s $dsddz$.

19:05-19:07 (2 sec) **Leo:** All right, in this case s is r so.

19:07-19:08 (1 sec) **Jacob:** Right.

19:08- 19:12 (4 sec) **Pause.**

19:12-19:27 (15 sec) **Leo:** So, the total function is triple integral *delta* r minus $rdzd\theta d$ whatever and the other one I didn't say.

19:27-19:38 (11 sec) **Pause.**

19:38-19:41 (13 sec) **Jacob:** All right and if we have them in order of $dzddr$, then z from minus infinity to infinity right?

19:41-19:47 **Jacob:** Because, it is infinite cylinder?

19:47-19:56 (9 sec) **Leo:** So, it is L in there, in this case it says it is 2 miles long so...

19:56-20:04 (8 sec) **Pause.**

20:04-20:06 (2 sec) **Jacob:** And then is from -2π.

20:06-20:08 (2 sec) **Leo:** That is true.

20:08-20:12 (4 sec) **Matt:** r is integrated over infinity.

20:11-20:16 (5 sec) **Leo:** So, we get $2\pi L$.

20:16-20:25 (9 sec) **Jacob:** The integral is in the second step. Integral is in part 2 Check the answer by integrated and find the total charge.

20:25-20:34 (9 sec) **Leo:** But we still need to find take out make it equal.

20:34-20:36 (2 sec) **Jacob:** Did we do this wrong.

20:36-20:43 (7 sec) **Leo:** No we just did the integral so we could find something in terms of and then.

20:43-20:47 (4 sec) **Jacob:** Oh, yeah but why does we need to do integral after you set up your.

20:47-20:51 (4 sec) **Leo:** I don't know we just follow problem C on that or something like that

20:51-21:01 (10 sec) **Pause.**

21:01-21:10 (9 sec) **Jacob:** Okay, so I wanna just make sure the total charge is equal to (Pause.)

21:10-21:21 (11 sec) **Matt:** It does just is just a delta function r minus d times C.

21:21-21:26 (5 sec) **Pause.**

12:26-21:29 (3 sec) **Matt:** It is in next problem that q integrated.

21:29-21:38 (9 sec) **Jacob:** That doesn't you still have [how am I trying to say]

21:38-21:43 (5 sec) **Pause.**

21:43-21:45 (2 sec) **Jacob:** The z term.

21:45-21:47 (2 sec) **Jacob:** That just a ring though.

21:47-21:54 (7 sec) **Pause.**

21:54-22:00 (6 sec) **Jacob:** So, that tells you it is restricted by this. It is a circle but, how tall is that circle?

22:00-22:02 (2 sec) **Matt:** It is L tall.

22:02-22:07 (5 sec) **Pause.**

22:07-22:09 (5 sec) **Matt:** Divided by yeah? Because, it is density.

22:09-22:13 (4 sec) **Pause.**

22:13-22:16 (3 sec) **Matt:** Does it a delta function has units? He is evaluating the answer.

22:16-22:20 (4 sec) **Pause.**

22:20-22:22 (2 sec) **Matt:** Because that is a linear charge density.

22:22-22:24 (2 sec) **Jacob:** Delta function is just one.

22:24-22:27 (3 sec) **Pause.**

22:27-22:29 (2 sec) **Leo:** No it can have units.

22:29-22:37 (8 sec) **Matt:** I don't remember.

22:37-22:50 (13 sec) (Jacob and matt check the books) **Jacob:** I think technically we are supposed to have been working of the spherical problems rather than our home work,which I would rather work on though.

22:50-22:58 (8 sec) **Pause.**

22:58-23:14 (16 sec) **Jacob:** He was reading from the books, consider the vector function e is equal to r. I don't actually read the sentences, so consider (He keeps reading from the book)

Appendix C

Categories and associated subcategories

C.1 Six major categories and associated subcategories

1. **Goals, motivations and constraints related to applying new changes in their teaching**

   - Beneficial for students
   - Institutional, practical and instructors considerations
   - Instructors affect-benefit and experiences

2. **Resources related to new ideas:**

   What resources instructors use

   - Online resources
   - Textbook-related resources
   - Books and other materials about how to teach

   How do instructors find resources

- Talking to other people
- Attending to workshops, conferences, community, seminars, departmental colloquiums, reading group
- Google and twitter
- Individual inspiration

Resources instructors would like to have

- Teaching materials
- Supporting people
- Kinesthetic activities
- Tools

3. **Types of new things that instructors are trying**

   - Instructional strategies
   - Content related
   - Tools
   - Assessment-evaluation resources

4. **Types of ways that instructors decide a new instructional practice is working**

   - Benefit Students– based on written evidence
   - Benefit students– based on instructor's intuition
   - Benefit instructors
   - Benefit Department/institution

5. **Challenges physics instructors experience related to applying new instructional practices**

   - Classroom practical consideration

- Engaging students
- Department cultural consideration
- Content materials

6. **Attitudes toward the implementation of new instructional practices**

    - Positive
    - It is hard
    - Changing incrementally
    - Nervous

C.2 Sources of data

- **Participant-A**

Participant-A is an Assistant professor of physics and astronomy. He teaches several courses including a mix of lower-division and upper-division course. It is his first month at this institution. He feels his university really values teaching, and his department, "which is why he was hired." He wants to do things differently for the students. He hopes to improve his teaching and their understanding. He values computer coding in the classroom, and he is interested in adding more coding to his course. He thinks coding is "another way of learning" and remembers how valuable coding was for him as a student.

Participant-A refers to borrowing an idea from other faculty as "stealing": *"I don't feel that I have the time to do that in the lower division, but you know, stealing as many ideas as I can from faculty that I know. That helps too."*

- **Participant-B**

Participant-B is a full professor of physics and has been in the Physics Department for 47 years. He is teaching an upper level junior/senior electromagnetism course and has taught the introductory electromagnetism course for many years. He describes himself as coming from a humble background. Participant-B talks about his motivation in keeping the failure rate low. A student committed suicide after failing twice, and that had huge impact on his views about teaching. He emphasizes that teaching is not at all valued at his department and feels the institution isn't doing enough to support students.

His teaching philosophy values interaction and listening to students. However, he still lectures in his upper-level courses because it's easier and faster to prepare for. He states that, *"I think as much interaction as possible, as much listening to the students to see what they're actually thinking as possible. I think you can't teach effectively if you don't do that."*

- **Participant-C**

Participant-C is an Assistant professor of physics and has been in the Department of Natural Sciences for more than a year. This semester he is teaching University Physics I, for the third time. Most of his students are in mechanical engineering, electrical engineering, and a few in biomedical engineering. He is also teaching one upper-level course, which is the Quantum Mechanics course for their physics majors. He always wanted to be a teacher. When he was a postdoc, he attended some teaching workshops where he learned about active learning. His university has a course structure where all instructors in that course do active learning and/or problem-based learning one day per week.

Participant-C thinks interaction is very important. He hates lecturing. He feels like the students are totally disengaged and not learning anything during the lectures. He believes, *"if they are engaged they are learning. If they are not, they are not learning."*

- **Participant-D**

Participant-D is an Assistant Professor in the Department of Physics. He teaches a large undergraduate course for freshman and sophomores. He works collaboratively with other instructors teaching the same course, in order to standardize the curriculum. There are six section in total and he teaches the last one. He thinks that he gets the most benefit out of it. The general components are pre-decided between sections, but the internal structure is up to each instructor. For example, they have to use some Clicker questions or do some practice problems in class. Participant-D was taught using very traditional methods, but thinks that active learning is a better way of teaching. He believes that active learning is easier for him – less preparation time – and more beneficial for his students.

Participant-D feels that it's very important to be a good teacher. He heard a lot about the latest ideas in the New Faculty Workshop. He chooses to try just-in-teaching methods this semester. He found it appealing and thought he could implement it easily without changing much of the structure of his course.

- **Participant-E**

Participant-E is a Distinguished Professor who has been in the Department of Physics and Astronomy for 34 years. She has no prior teaching experience besides graduate school. Her teaching philosophy was pretty simple: students need to be engaged and teachers need to listen to their students. She views herself as an evangelist of interactive teaching and she transformed the course. The teaching culture in her department has changed to be more teaching-focused and she feels this is a direct result of her work in these course transformations.

Participant-E believes strongly in the apprentice model for learning about interactive teaching. Good teaching is important to her because, *"That's what we're here to do. If you're not trying to be the best teaching you can be, then you are not fulfilling your professional responsibilities. Who wants to think of themselves as being a person who would not do the right thing?"*

Participant-E would like to have a handbook, *"PER in a Jar"*, to introduce physics instructors to ideas about active learning, and she said, *"Here are the important things that you should be doing in a class" and "teaching this way".*

- **Participant-F**

Participant-F is an Associate Professor and has been the Department chair for 22 year. He has no prior teaching experience besides graduate school. He teaches several classes this semester. He is teaching Physics for Life Science Majors, a course which he developed. Prior to this course biology majors were required to take the same class as the physics and engineering majors and most life science majors were struggling. This course was meant to be in between. Not as much focus on mathematics, but it did go beyond the traditional algebra-trig based physics course. Participant-F is experimentalist and he believes experimental techniques are very important.

Participant-F cares a lot about supporting women and people of color in physics. He tries to move the department towards a vision of more inclusiveness. The biggest influence on his teaching is interactions with his diverse students, who have different ways of thinking.

- **Participant-G**

Participant-G is an Associate Professor in the Physics and Astronomy Department. He has been engaged with education since 2014. He is teaching ten sections of an introductory physics lab class that's taken mostly by pre-meds and life science majors. He is coordinating and designing the course. He manages an instructional team of four TAs and five LAs. He doesn't think about himself as a PER person. He felt inefficient while lecturing and feels much better when he moved to a more active environment.

Participant-G says he has an apathetic department that doesn't stop him from trying risky teaching ideas.

- **Participant-H**

Participant-H has been a lecturer in the Physics and Astronomy Department since the spring 2007. She also runs their Supplemental Instruction Program through the Center for Science and Mathematics Education since 2016. She seems very motivated to be great teacher. She is mostly assigned to teach one or two lower division physics or astronomy courses. This semester she is teaching Physics 101, which is their single semester conceptual all-of-physics class. Her class is a combination of lecture, Think-Pair-Share questions, and in small group practice problems. The last time she taught physics 101 was spring of 2015. She was creating her own worksheets (4–5 over whole semester) for this course. Now she uses Ranking Tasks, so students are doing a few per week (20–30 in the semester).

In terms of pedagogy, she thinks students need to practice physics. She likes students practice during class, instead of outside the class. She decided to switch from a fast paced lecture course to a more moderate paced group work course. That transition make her class slower. By the end of the semester she had to cut out some topics that she thinks students don't really need.

Being a lecturer also affects her in that she doesn't have access to money for professional development, conferences or workshops. She has to pay out-of-pocket for these and her time isn't compensated. She's part of several faculty reading groups, including Faculty Agents of Change on social justice. Her students come from diverse backgrounds and she's been learning to understand her students' needs.

- **Participant-I**

Participant-I is an Assistant Professor on a pre-tenure track. This semester he is teaching the Physics for Life Science lecture and the labs along with it. This is his third time he is teaching this class. He thinks his college values teaching a lot, but he's worried about how he is going to do enough scholarship for his tenure. The room where he teaches makes him feel very constrained. He wanted to use whiteboards, but the whiteboards are too big for the tiny tables that are attached to the desks, so he doesn't use them.

Participant-I likes students to drive conversation in class. His students are reluctant to engage in the class activities and to give him responses. He doesn't have a toolkit for dealing with students not participating in class.

In addition, he values feedback. From the Guess-Minute-Papers' responses he found that students like in class examples. However, he doesn't like examples because he is not getting any feedback from them. So he switched to posting a problem, having students work in small groups , and walking around to facilitate the process of problem-solving.

- **Participant-J**

Participant-J is on his tenure track. He teaches E&M, astronomy, some labs, and a senior seminar on cosmology this semester. He had some prior teaching experience as a graduate student and as a postdoc. He usually uses power point to teach astrophysics. He lectures from the slides which are image heavily and light on words. He usually uses videos and animation to demonstrate concepts in his slides.

Participant-J really tries to engage students in class activities. Most of the ideas are his own: *"I just sit around and think about these things sometimes. It's usually when I'm taking a shower, or when I'm falling asleep or something."* The small group activities are one of the new teaching ideas that he tries this semester. He came up with this idea by himself.

Resources that he mentioned as important for getting new ideas for teaching are the textbook by Comins and Kaufmann, observation of other faculty and talking to experts, having more representative textbooks, natural history museums, astronomy blogs, databases about astronomy, and YouTube videos. He says that in order to find new online resources such as demos or videos, he uses Google.

- **Participant-K**

Participant-K has been an Assistant Professor of Physics for 3 years. She has a lot of teaching experience. She never mentioned that this earlier teaching experience influenced her current physics teaching. This semester she is teaching Classical Mechanics for freshmen. She is teaching two sections of a huge first-year course that has up to 1400 students and 35 faculty. Each section is only up to 24 students. There is a course director that determines the course structure.

Participant-K never talks about herself as a researcher, but she cares a lot about data from her students and research results around teaching methods. After she heard about result of the worksheets study at NFW, she chose worksheets as the new teaching idea. It makes sense to her that worksheets would work because they make students think about things in a variety of ways and that they work together on them.

Participant-K read *Five Easy Lessons, Strategies for Successful Physics Teaching*, by Randall Knight as a graduate student. She thinks this book was very influential on her teaching. She says it is an "awesome book", because it is about physics teaching, not just teaching in general. An important part of the book for her was seeing the importance of connecting physics to everyday experience.

- **Participant-L**

Participant-L is an Associate Professor in the Chemistry Department. This semester she is teaching 3 sections of Algebra-Based Physics 1. She has been teaching this class for 10 years. Over this time she thinks her class has moved away from lecturing and to more research-based instructional strategies. She sees herself as a facilitator now.

She thinks that for students who aren't going to take another physics course, the most important thing is their positive feelings about physics. So, she tries to listen to them and meet their needs.

Participant-L has a lot of background knowledge about how people learn. She thinks a lot about equity and inclusion. She tries to be extra supportive to students of color in her classes who are struggling.

- **Participant-M**

Participant-M has been a full-time Astronomy Instructor for 14 years. She teaches an astronomy 1 lecture and astronomy 1 lab. She doesn't really talk to anyone about her teaching except a part-time instructor once a year to go over assessment results. She feels the reason for this is because everyone is "stuck in their own field".

Her philosophy is about asking students questions, getting them to think about them first, and then telling them the correct solution. She didn't like how she was taught as an undergrad in physics, she says, "too much fast math on the board, no demos, no conceptual connections". She didn't want to teach her students like that, because she didn't understand when she learned that way.

Participant-M thinks working as a group is important, she says *'if they can explain it, they can learn; reinforce the concepts because you learn by teaching."* She made an interesting distinction between "lecturing" and "teaching". Lecturing is telling students things and presenting the facts. Teaching is doing demos, using in-class activities, asking questions, and getting them to think.

- **Participant-N**

Participant-N started as an Adjunct Physics Lecturer for 3 years and now she is a lecturer with potential security of employment. Her focus is on the Undergraduate Physics Program. She is teaching 5 courses this semester. She says it is very important for her to meet with local collaborators to bounce ideas off and observe what they do in class.

Participant-N thinks the more engaged students are, the better they'll learn. She is enthusiastic about trying new things. She wants her lecture time be more beneficial for students. To do this she tries different things such as modifying lecture slides by using worksheet style slides, Clickers questions, demos, and etc. Her students' opinions about her new teaching ideas is very important for her.

Her undergraduate learning experience did not influence her current teaching. However, her experience as a graduate TA did influence her teaching a lot. She knows that not all students learn like she does and she need to try lots of different teaching strategies.

- **Participant-O**

Participant-O is a Master Lecturer who specialize in teaching and curriculum development. He is teaching two sections of an Algebra-based physics course this semester for pre-med and life science students.

Participant-O has a lot of teaching experience. He has been teaching intro-level physics class for 22 years. He deeply enjoys interacting with students and getting to know them. He gets a lot of ideas from high school teachers through their teacher-in-residence program. He attends AAPT twice every year and always walks away with new"ideas".

In order to have a fun and interactive space in his classroom he is motivated to try new instructional strategies. They have pre-class assignments, where students watch videos that he created, to answer some questions before the session. He looks at their answers and feedback before class and shapes that day's lesson around them. He always mentions a few of these in class and responds to them explicitly.

His teaching is inspired by his father, who was a teacher, and an influential professor he had as an undergrad. From them he learned how to listen to students.

- **Participant-P**

Participant-P has been an Assistant Professor in the Department of Physics for 4 years. This semester he is teaching two sessions of Introductory Mechanics and Upper-Division Applied Solid State Physics. He thinks the department, the college, and the university value good teaching and that they are all very supportive.

Participant-P wants students to be engaged and have a better experience than he did in undergrad. His biggest challenge is getting students involved in classroom activities. Another challenge is the difference in students' background knowledge. It's hard to "cover" material when some students have the prerequisite knowledge, and others need him to teach it to them.

Participant-P wants teaching materials and assessments to use in his upper-level Solid State course. There's a lot of resources for intro-Physics courses, but he didn't see anything for upper-level Solid State courses.

- **Participant-Q**

Participant-Q has been an Assistant Professor for 3 years. He teaches Mechanics in the fall and E&M in the spring. He has a lot of teaching related knowledge and experience. During his PhD he did a teaching fellowship. While he was in undergraduate he considered becoming an education major and he took some teaching classes. He took one STEM teaching courses and that was the first time that he was formally introduced to the ideas of active learning.

Participant-Q is very enthusiastic and motivated to teach well. He wants to keep students awake in the classroom and help them learn effectively. He participates in every teaching activity in is department, such as weekly meeting with new physics faculty and workshops at the teaching and learning center. People are the main way he learns how to teach. So, he asks questions and seeks out people to learn from.

Participant-Q tries to keep his lecturing to a minimum and find a balance between new instructional methods and lecturing.

- **Participant-R**

Participant-R has been a part-time Lecturer since 2013. This semester he is teaching an Introduction to Experimental Physics course, which is usually taken by sophomores and electrical majors. Participant-R would like for his students to interact with as many measuring devices as possible. He has developed a lot of lab manuals. He says, "it's an ongoing process". Some of the lab manuals come from the equipment manufacturer and the rest he's come up with himself.

Active-learning is important to him. He mentioned a tension between rigor and active learning. He thinks active-learning gives students an opportunity to share what they are thinking with fellow students, even if they are not forthcoming to share that with him. However, upper-level courses need rigor, so they can't have as much active-learning.

Being a part-time lecturer doesn't influence his teaching very much. The department has given him lots of freedom to develop courses how he wants to. He doesn't talk about his teaching with other people very much. He mentions that he had observed some of his colleagues teaching, but didn't have time to follow up and ask more about that.

- **Participant-S**

Participant-S has been a Professor of Physics for 14 years. He taught Intro-level and Upper-level courses. This semester he has only one class, which is a sophomore level Circuits course. He teaches both lecture and lab. He taught some courses such as upper-level Quantum Mechanics and upper-level Mechanics in the past. These are courses that he has experimented with and made changes to.

Participant-S thinks deeply about why his class should be more useful for students than just reading the textbook. What he is trying to do and why is important to him. *" Why should students come?"*, his answer is, *"it's valuable to work together with other students, facilitated by an expert."*

His department has a lot of emphasis on active-learning, which he is happy to use, but he is reluctant to create his own materials. He thinks it's not where his interest lies and so he doesn't do it. He got some new materials from other sources, such as tutorials from faculty members and online resources. To pick the course materials he was looking for "fun" and "compelling" resources to use in his class that will fit well with the textbook he was using.

Being an experimentalist he wanted to incorporate a lot of experiments and labs. He thinks he has learned a lot of physics by doing problems and trying to solve them. He wants his students to learn the same way. He thinks that problem sets and lab skills are a very important part of learning physics.

- **Participant-T**

Participant-T has been an instructor for 6 years in his current institution. He was a Teaching Assistant for a lab when he was a graduate student. He was an Assistant Professor for 4 years before his current position. He taught mostly Intro-level classes for engineers and only a modern physics course once.

Good teaching is important to him. He says, *"because that's my job"*. Also, *"I wanted the student to get something that they couldn't get from reading the textbook."* He reads Physics journals about good teachers and effective teaching. He finds interactive teaching to be more fun and students enjoy it.

Engagement is the main way he decides whether his teaching is working. In the past he thought that having a good lecture was the most important thing, but students can just get that from reading the textbook. He has changed his teaching methods and now wants students to take charge of their own learning. Participant-T had a sophisticated explanation about why group work and student-centered teaching is important. He described his role as a facilitator. He spends most of his time listening to students and asks them to work as a group. While students are solving a problem he is trying to listen to them, catch misconceptions, and finding a common theme between the different groups.

Being an instructor rather than a faculty influences his teaching as he does not have a lot of choice about what class he gets to teach. Participant-T teaches where they need him. He has had some experience teaching intro to modern physics courses, which are a very heavy lecture-based course. In these classes he gave less lectures and instead tried to have discussion around the topics. *"I found those were the classes that I had the most fun with. And like, I mean, the students seems to enjoy them."*

- **Participant-U**

Participant-U is an Assistant Professor who just started teaching this term. He is teaching a Classical Mechanics 300-level course and a couple of Introductory Physics labs, including mechanics, kinematics, and accelerations. There are students coming from all different backgrounds and going to different majors. The department want to improve and change their teaching methods, so it is very focused on the teaching.

He is a very thoughtful instructor that wants his students to learn a lot. Participant-U has learned about teaching from colleagues in the past, but when he has a challenge he thinks of the solution on his own.

He seems to get all his ideas about whether new methods are working from the impressions of his students through surveys, watching them work in class, questions during office hours, etc.)

When he was a student he made sure to read the material in the book before that corresponding lecture and it helped him a lot. He was more confident, relaxed, and he had a greater understanding of things. He says, *"I really liked the idea of having the students warm up before coming to class."*, he thinks they learn better. If the student has already read the material then he doesn't have to go over again and instead he can use this time for group working.

- **Participant-V**

Participant-V has been an Assistant Professor of Physics for two years. He teaches four classes per semester and also does research with the students during the summer. He is teaching an Upper-level Optics, Principles of Physics, and 2 lab sections this semester. He thinks teaching is the most important thing in his department and university.

He's in a reading group with faculty across his campus where they are reading a book about effective teaching. It has been highly influential for him.

Participant-V cares about changing incrementally and not suddenly.

Participant-V believes the evidence from educational research. He says *"I've seen data on it, lecturing can be dead time."* He sees himself moving toward less lecture and more to active engagement activities, but he says that he can't let go of lecture completely. He cares about changing incrementally and not suddenly. Participant-V is getting his ideas from people. For example his friend uses whiteboards so he wants to try them.

His main challenge is students engagement. To address this issue he tries more problem solving, but *"I don't make it where working together is required. If someone wants to sit there, if they're just an introverted person, I don't think I should change that. That's them. I think they're just shy."*

- **Participant-W**

Participant-W is non-tenured faculty and has been in the Physics Department since 2001. At present she is a term Associate Professor about to apply for full Professorship. She has been exclusively teaching the general education courses in Physics and Astronomy. Currently she is teaching Physics and Astronomy for non-science majors, pre-med, and biology majors.

The biggest influences on her teaching are her colleagues and her seeing physics in the world around her. She watches colleagues teach and learns from them.

She thinks the biggest change is that she is much softer with students now than she was when she first started. Participant-W says the students were "petrified" and was trying to make physics not so "scary" to them. She cares a lot about being a good teacher, especially connecting with students from different backgrounds.

The changes she was making were all around the content and how students understood physics concepts, not the "teaching methods." They all felt like small changes. Her teaching philosophy is about wanting students to see physics in the world around them and use their imaginations.

C.3 Examples from the interviews for statements fitting into the category

C.3.1 Goals, motivations and constraints related to applying new changes in their teaching

Beneficial for students

Participant-Q There's a variety of motivations for active learning. The most basic and pragmatic of which is keeping my students awake. They're scheduled from like 6 : 00 or 7 : 00 *a.m.* until anywhere between 8 : 00 to 10 : 00 *p.m.* and then, somewhere in there, they have to figure out where they're doing their homework and studying and being 19 year old. So, many of them are very, very sleep deprived.

Participant-P I do think, it's really important. Looking back on, like I said, looking back on my undergrad. I think there were a lot of things that I personally missed out on.

Participant-W That was really great, because students were much more engaged, and especially when you have summer course lectures that last three hours, kids are tired, they fall asleep. If you space it right and do activities, that keeps them engaged and awake.

Participant-N Seeing with my own eyes the students' experience with something and thinking. Okay! Well. The more engaged, the more they're working with material, having to question things for themselves, the more beneficial, I believe it is.

Participant-B When, I had been lecturing before as the sole lecturer, I would get 40 % attendance, and I would fail 10 to 15 % of them. I said, look, I'm gonna make them come, because I don't want to fail 10 to 15 % of them. I made them come.

Participant-A But, I know, I need to at least get them engaged.

Participant-A But, I'm having them get up, I'm having them move around the room a lot more. I take them outside.

Participant-K You really are almost like a comedian or an entertainer up there, just trying to keep them awake. They're hardly getting any sleep, it's like five hours, maybe, a night.

Participant-R Letting the students engage in a back and forth.

Participant-C Where I post some questions, they interacted with me, and then I let them interact with each other.

Participant-B I think most of the junior faculty who teach in this course realize how much better this is than lecturing the students.

Participant-E That engaging with the students, and getting the students to engage with each other is critical to learning.

Participant-W It's always been my goal to make learning fun. But, at the same time, to make students understand that fun doesn't mean that you don't have to work hard. The fact that, I can present something in a funny way may make it actually more memorable and better understood, more nuanced. But, that doesn't mean that just because, I'm funny. I'm not gonna acquire serious work from students.

Participant-C Student outcome is important, but also how they feel about it is also kind of important.

Participant-N I just want my student to learn better.

Participant-A I wanted to do things differently for the students to hopefully improve my teaching and improve their understanding.

Participant-B After observing L. M. and B. B. class, so that's when, I decided that lecturing really wasn't a very good way to teach because it. Just obviously, I was never listening to the students enough to know what problems they were having.

Participant-W My goal to make learning fun. But, at the same time, to make students understand that fun doesn't mean that you don't have to work hard.

Participant-Q Also, just useful learning practices, things that actually stick in their head. Motivating them to actually internalize what they're working on is a big reason that I have sort of the concept side of the active learning things that I do in the classroom. So, as opposed to me just sort of spouting off what I think is important to them. I like them to sort of chew on the idea before we start digging into it.

Participant-N So, incorporating Clicker questions helped, but they could do more.

Participant-Q Motivating, remembering and practicing are the reasons why I try to harp on active learning as opposed to me just lecturing in front of them.

Participant-Q So, motivation is another big aspect of why I try to push active learning. Really, one of the, I think, most productive aspects of it is practice. It's an environment in which, I can get them practicing quantitative problem-solving in a way that's not like them sitting in front of Chegg and just copying down homework solutions. Because, if I just give them homework problems to work on, they're going to find solutions somewhere and basically, just convince themselves they're doing something by copying those solutions down. So, here, I at least have them in the classroom and I can force them to work through these problems and get some good practice in, ask questions of their peers and myself. More often it's their peers than me, but, I am walking around the classroom constantly, interacting with them, seeing their progress, seeing how they're doing and trying to push them in a certain direction if they're straying really far off. Or, just let them sort of wallow in whatever struggle they have until they can figure out what the answer is.

Participant-H In terms of pedagogy, students need to practice.

Participant-G W. and coworkers, that labs are not, and others, that show that, at least traditional labs, didn't help students learn concepts any better. But, we know that they have some purpose, right! So, what was that purpose? And so, I guess the main conclusion I drew from that little bit of work is that it's really more about students learning science process and practices.

Participant-O We gradually just added interactive elements. Then we introduced Clickers to the class, just to promote a little bit of discussion among the students.

Participant-O We just tried to make it as interactive as we could. But, it's hard to do that in a lecture environment. So, they change the environment into the studio space in the early 2000s.

Participant-C I like the interaction. I'm the kind of person who likes interaction.

Participant-C Where I post some questions, they interacted with me, and then I let them interact with each other.

Participant-C I believe that you know, if you could reverse that role and make the students interact with you during class, that would be better. So, that's why I don't like traditional teaching anymore.

Participant-A I like them to be able to work with each other, in front of each other and I like that they get the ability to see different peoples thought process and responses.

Participant-B Later on, we would say, look, it's well known that if you are in a course that's interactive, you learn more than if you just sit passively and listen, and we would quote the research. We tried to make it clear that we were doing this so their learning would be better. It was we'll go with the research.

Participant-A I try and keep them short and interactive to at least keep them engaged.

Participant-A A lot of the tutorials tend to be interactive either read and answer questions or conceptual or they have some where you have to match this concept to this definition or something like that. So, anything that was more conceptual, interactive, anything that I thought was gonna be a little bit more engaging, I've left that for the pre-lecture stuff.

Participant-P One of the other things I always tell myself. Is one of the goals of this class is, if at the end of it, the students can have a meaningful discussion that takes place in reciprocal space, that's good for me. Because that was always a hard time.

Participant-T After, I've done that for maybe two or three semester, I found that it wasn't fairly effective in getting the student to engage.

Participant-T I feel like there's sort of this, you know, this shift in like understanding whenever a student talk.

Participant-T So then, I decided that I'm going to be much more intentional about getting them to talk to each other.

Participant-J Every other class they do some small group activity, and then I have them take a photograph of them on their phone, and then upload it to Moodle to show that they did something.

Participant-O This is on WebAssign, the online homework system we use. There are links to the chapter section, the e-book, which are on WebAssign as well. The students can choose to look at the video, they can choose to look at the e-book, all things like that. It should take them 15, 20 minutes.

Participant-I Maybe this is a personal bias or something, but one of the things that rings true to me is there needs to be some evenness in your life and part of that means exercise is important, so much so that if you've got a lot of tasks that are not exercise-based, missing out on some of those tasks in order to get exercise will overall lead to an overall better structure.

Participant-I That when you implement something explain why you're implementing it and the goals of it, and I have found that when I try and do that, the main thing I get from the students is, why are you talking about teaching and not teaching. Does that make sense?

Participant-O I usually pick some student's comments to respond to. It gets that dialogue going, which is nice.

Participant-G A motivating factor that we just wanted to serve the students better.

Participant-G It's just really rewarding to see students, especially students who struggle kind of, be able to, not necessarily get where they want to go, but at least take steps in the right direction.

Participant-P A lot of the, so I try. I've tried to be really good with this course. I had some course releases, the last time I taught it. So, that might also be why it went better. Because it was the only course on my plate. But, and it was also after using the Folk. The back down line committee, so I had a lot of thoughts on it. One of the things I tried to do better, is have course learning outcomes clearly defined.

Participant-B In my opinion, the institute does not do enough for the people who really struggle. We let them in. They don't let themselves in. We let them in and a lot of them sink, and we don't do enough to keep them afloat. TEAL, physics, everybody is afraid of physics. It's the most unpopular freshman course. It had the reputation of failing a lot of students, and I changed that. Yeah, no. It was worth six years of my effort, but it's not obvious why I did it unless I tell you what I just told you.

Participant-V You have an ethical obligation as a teacher to seek out the best way to do your job.I think it's a duty to stay up to date.

Participant-T Having been sort of serious teaching for about 10 years, my idea of what my role as an instructor has evolved over time.

Participant-P I'm motivated to make sure that I'm doing a quality job.

Participant-T But, I mean, I guess I wanted the student to get something that they couldn't get from reading the book.

Participant-B We had this course where we were failing 10 to 15 % of the students, and some of them died because of it. that's why I did it. The failure rate is down, and I tell myself that doing this has saved the life of at least one freshman so I'm even.

Participant-G It's my job.

Participant-J I spend a lot of time staring at the sky. Way more now that I started teaching astronomy. And I tell my students this, and I think it's super important to astronomers, like people who are teaching astronomy and taking astronomy, to just pay attention to the sky.

Participant-W I want them to use their imagination. I want them to start seeing the physics around that I'm seeing.

Participant-I Since, I am less concerned about their learning the material and more concerned about thinking scientifically. Thinking scientifically and maybe changing attitudes toward science.

Participant-P I thought that was a pretty good idea, students seemed to like it. I thought they got to go more in whatever they were interested that tied the solid state.

Participant-V I think the book basically said, you have evidence that something doesn't work so why are you gonna keep doing it?

Participant-V I've seen data on it, lecturing can be dead time.

Participant-H They had run some studies that they'd talked about in the workshops where ... showing actual data that lecturing only gets you so much as far as learning gains are concerned.

Participant-U I like to continue doing this if I get a good result. If I don't I will have to think about that.

Participant-H I was very hesitant to implement some small group work, that I hadn't test run before with a class, and then have everybody get horribly, horribly stuck, and have that all be on one person, me, to answer their questions.

Participant-B I still remember sitting in the classroom, a SCALE-UP classroom, behind some students. We were observing L. M. has a workbook about experiments that you do. They had no instruction on this and already had told them what they should expect. I was sitting there and thinking, "Oh, I know exactly what the problem they will have is they'll V cross B or IDL cross B and they'll get the wrong direction." It'll be into the board instead of out of the board. I know that's the problem. Instead, the students spent 10 minutes talking about whether the wire would be attracted to the magnet or repelled from the magnet. Something that had never occurred to me that they would think.

Beneficial for instructors

Participant-O It's a little crazy. I really enjoy it. It keeps changing. It keeps being fun... I have fun doing that. The studio environment is great because you get to know the students so well.

Participant-G It actually just felt better. It also felt better to give up a little control of the classroom. So it felt better and it was more fun.

Participant-E Well, I never knew this could be this much fun, and I won't ever just straight lecture again, because that's not nearly as much fun.

Participant-E I looked at a lot of things, a lot of the stuff that's in the literature. Going the SCALE-UP direction seem most compelling to me. And that, of course, was partly influenced by the fact that we had two people here who had experience with the SCALE-UP, or a modified studio model, and knew very intimately and deeply how effective that is. So, I'm sure that had a lot of influence in my thinking.

Participant-D But, this is something that just in teaching, I found I had not been doing before, so let me try that. So, I found that kind of appealing to me.

Participant-B Because, I had a lot of ego involved in it, and I thought it was the best thing to do.

Participant-B I think as much interaction as possible, as much listening to the students to see what they're actually thinking as possible. I think you can't teach effectively if you don't do that.

Participant-W When I design problems for my classes, I know what I want them to learn.

Participant-T I think what we're all about is to change people's belief. I mean, the content is basically the evidence that we use to build up this belief system that we have.

Participant-T My idea of what an instructor should do have evolved to what I want is to facilitate their self-learning, that you know, like a lot of time what I say doesn't make as much sense to them as their peers say. So, my job in the classroom is to make sure that the misinformation don't get out of hand.

Participant-P I knew I wanted like that engagement and ya know teachers are no longer xerox machines, or reading you textbooks. So, I knew I wanted, I've known since started teaching, I wanted that to be more than just someone reading a textbook, and lecturing concepts sort of thing.

Participant-T I want to make it as obvious to the student as like this is what I want to do.

Participant-T Because, what I don't want is for a student to give up early.

Participant-T Well, that's my job as an instructor. I mean, I don't have research, so that's all there is.

Participant-L I feel like the class is an example of what I want them to be doing. So, I try to set that class up in such a way that I hope that they can pull things out of it, so that when they're teaching that they'll have these memories in their head of what it looked like and how this can be positive.Yeah, so those are the reasons teaching's important to me. I mean if I'm not gonna do it at the very best, if I'm not gonna invest the time and the energy to make it really worth- while, then why am I here?

Participant-P One of the things I tried to do better, is have course learning outcomes clearly defined.

Participant-A The desperation of teaching a biology class last year and I needed to see what resources I had available and the school automatically used Mastering with their students.

Participant-H So, a usual day, I'll start off by introducing the topic for the day. I try to keep lecture to half of the class time or less, if I can help it. We have 50 minute class periods Monday, Wednesday, and Friday. So, I'm trying to lecture for 25 minutes or less.

Participant-M Well, because the other way that I was doing it was really instructor intensive.

Participant-S I guess I would say the biggest influences on my teaching are being an experimentalist and wanting to incorporate a lot of experiments and labs. I've done that in a lot of the courses that I taught, like introductory mechanic, incorporating labs in there because I'm experimentalist.

Participant-T I guess Physics Department are always fairly hard set in their way, but I think over times and with new faculty coming in, we have sort of gotten to sort of critical mass. Not substantial change, but there's at least critical mass went into the faculty that say, you know, there's all these new education research that I've heard about who would just try some of these things. So, that's also sort of this, you know, the faculty is just changing demographic and newer, and more open.

Participant-O In fact I did different things in my two different sections. We're running a bit of an experiment this semester. We did it last year and we're doing it next year, too. We're comparing simulation based experiences to hands on experiences. One of my groups, we're doing a simulation yesterday, and the other group was doing the hands on version of it. Other days there's a bit of lecture, but the room is designed to minimize that.

Participant-T I would like to be more self-reflective and be more like, you know, thinking about what my student are going through and things like that.

Participant-G I felt like I was developing relationships with my students more. I felt like I didn't have to be perfect, and that just like kind of felt, I guess, a little bit more free.

Participant-P Basically every time it feels like things aren't going well. Or could be going better.

Participant-A It's not the best feedback but it's immediate feedback and I like that.

Participant-D I thought it was really nice because we can get active feedback from the students immediately.

Participant-I I guess minute papers is the buzzword, where I have daily feedback where I ask them to turn that in.

Participant-E If it's easier and they can see, "Yes, this really does work." And once you've done this kind of teaching, you come to realize, "Yes, this really does work better."

Participant-N She also introduced me to group exams. I had heard about group exams, but the idea, like how do they even work? Well, she has experience with it, so that first summer she was teaching with us, I was also teaching a summer course and I was totally inspired by her, and did group exams. It worked really well in my class. I'm trying to see this semester if it can scale into the larger class. She's doing group exams in her class, and she's got group exams this week, so I'll be able to sit-in and kind of see how that goes.

Participant-B But I saw SCALE-UP and then I patterned what I was doing very much after what SCALE-UP done. The format, the fact that the tables were seven foot in diameter, all that, that I've got nine students at a table, all that just SCALE-UP.

Participant-I I actually have a fairly good interaction with another of my cohorts. So he's also in his second year here at Union in the English Department, and we've actually sat in on each other's classes. I can talk to him about stuff and one of the things that we're discussing, that again I'm not gonna implement until after I get scholarship and other stuff done, is he does some stuff in his class that implements improve ideas, ideas from improve theater, that I just think are wonderful and can we get more interactive in physics classes doing the same type of thing.because we have a much more specific goal a lot of times than they do in English classes. But still, I really liked it.

Participant-N She has experience with it, so that first summer she was teaching with us, I was also teaching a summer course and I was totally inspired by her, and did group exams.

Participant-F But ideally what we would have them do is sit in on a class during the week where there's an experienced teacher teaching that same class. They sit in and observe before they do it with their class later on in the week.

Participant-D So, we also have actually a teaching mentor. That's what I was going to tell next. So he comes to my class, and then he sits in my class, and he gives me tips. Like last year he did once, and then I went to one of his classes, to observe how he teaches. And he's teaching a much bigger class. It's like 250 students. He's in science and psychology. Yes the content is different, the class structure is slightly different, but I try to learn how he's interacting with his class. And then I try to kind of follow some of his suggestions and advice. Yeah.

Participant-B We will put them behind more experienced lecturers so they can come in and observe somebody else doing it before they get up to do it.

Participant-I But, I would actually not just like go and observe an individual class, I would go and sit in and watch them teach multiple classes.

Participant-E So, the idea that there is a science of teaching and it has a place in Physics Department for [Inaudible] is something that has come about, partly because we have this bunch of energetic and very skilled and engaging PER people now among our [Inaudible] faculty, and people see the value of.

Participant-E Well, as I said, the experiences of getting to know the PER committee, which is I was not acquainted with before that when serving on that task force. That really was the most profound influence on this is I came to know these people, and came to hear about what it is that they do, and it all made a whole a lot of sense to me.

Participant-E Often, they'll come and ask either me or some of the PER people saying, Where can I find materials on Quantum Mechanics?

Participant-F Community colleges, we're very supportive of one another here, so it's a great environment to work in when you get a good group of folks.

Participant-P Know motivated by the FOLC workshop or anything. definitely heard lots of discussion and ya know, I don't think I would've had the idea, had I not been involved there. So like, there were a lot of useful discussions, like I remember there being a lot of stuff on labs and different things that just haven't, I haven't done those style of courses.

Participant-A When we got to the Paradigms, it was much more interactive. They always tried to have us do something on the computer, have us do an activity, have us work in groups, not just lecture.

C.3.2 Institutional, practical and instructors considerations:

Participant-S Our department has a lot of emphasis on active learning and in the classroom, which I'm happy to use, but I'm less excited about creating it.

Participant-U So, this is a small, very small department, and that the good thing is that they want to improve it and change it. So, it was very focused on the teaching, just basically teaching. And it seems that some- that it hasn't evolved in many years. And now there is a wish to evolve and adapt things and get new ideas.

Participant-F Well, our department is going through a transformation right now, and I'm pleased to be a part of it and leading that transformation. Because we just had some transfers and some retirements out of the department for folks that were really kind of stodgy about how physics should be taught and what physics is, and their general attitude was that physics hasn't changed in 30 years, so why should we change what we're doing, not really understanding that not only is that not true. I get what they're saying, but even if that were true, it's the students that are changing.

Participant-T So, we had the same chair for a very long time, for like 12 years. And then we changed to a new chair, and then now we're actually on the second chair after the change. So more normal four or five years term as opposed to 12 years. So the change happened when after the transition, so you just have new people coming in and they want to try a new thing.

Participant-T Of the cynical reason that the central office wanted us to go higher up in the US news and reports ranking, and having a huge lecture course, you know, the student per faculty ratio is too big. So, we could take a huge lecture course and make it small at least in some accounting way, and that will make us look better and then we'll go up in the ranking. So it's sort of like all those things.

Participant-B That's a lot of the motivation for us doing this because there was a lot of pressure outside the Physics Department to not be failing so many students.

Participant-B The reason the Physics Department was willing to let me do this was the failure rate in freshman physics was very high compared to other institute requirements, math, chemistry, biology. They would have failure rates of 5 percent.

Participant-B Predominantly the way they teach at my institution is they lecture, and he lecture because it's the easiest thing to do. He got the departmental teaching award, which is basically the students like the course. We still base tenure decisions, that part of the tenure decision that depends on teaching, which is 15 %, we still base that 15 % on students filling out a questionnaire saying, I like this course.

Participant-R I have tremendous freedom here. But, I hope I'll be around, because your designation is a part-time, so you have to be aware of that. But I think, having said that, the department has been quite generous, generous is not the word. They've allowed me enough freedom to develop these courses, to teach these courses.

Participant-B The department was very supportive. Remember, the department had been getting beaten up for 30 years about their failure rate, so they were really glad to see me doing something.

Participant-V The college I'm at, it's a largely teaching based endeavor. It's not like a research university. It's a lot of our responsibility so it's good to see, I like that everybody takes it seriously and wants to talk about it and figure out what works and what doesn't. I think it's good. It's a nice environment.

Participant-Q There's a ton of support here at the my institution or at least, I don't know, I would venture to guess that at most institutions that value teaching, if you look for it, there's a lot of support.

Participant-Q let's see, as far as flexibility goes, we're allowed a good amount of flexibility in the way that we teach the course. There's a syllabus that we should adhere to just in terms of timing, and there's a common final. But, we make all of our own during the semester exams. And we also have control over all of our own labs.

Participant-B Because after the first year, we were not failing as many, and that gave me a lot of freedom because we weren't failing as many.

Participant-I For institutional support for teaching I'm finding great institutional support. I have been sent to the New Faculty Workshop. I was sent to a, they called it BUFFY, Beyond the First Year. There's also an AAPT, I guess New Faculty Workshop is AAPT and APS, but the AAPT also does a Beyond the First Year lab thing. I've been sent to that. Very positive experience. I've got support for like if I want to buy stuff I have, not cart blanche, but they're not really picky on the budget, right? If I want to buy some new lab equipment, if the lab equipment is cheap it's like, okay, let's get eight sets. If it's not cheap, let's get one and make sure it works. But it's still almost always, yeah, let's go ahead and try it. I haven't found any institutional resistance at all.

Participant-P Like the college and the university really value, they actually put probably like 60 % of that on, like if you, I get the impression that if you don't have some, like if you don't excel at teaching, ya know even if you were to publish like three papers a year. Odds are ya know, that teaching could come back bite you in the ass. So, yeah. I think they not just superficially, but it's actually valued. Ya know, there's a lot of support to attend conferences. We have a campus faculty workshop thing. So there's constantly, like every semester you get an email or two, about like, oh we're having a workshop on like flipping classrooms, or doing things like this. Lost of support.

Participant-T I think people wanted to make changes and there was soft money that would allow them to hire two new instructor. And then, they decided that was the easiest thing that they could do that would get to what they wanted.

Participant-I Very positive experience. I've got support for like if I want to buy stuff I have, not cart blanche, but they're not really picky on the budget, right? If I want to buy some new lab equipment, if the lab equipment is cheap it's like, okay, let's get eight sets. If it's not cheap, let's get one and make sure it works. But it's still almost always, yeah, let's go ahead and try it. I haven't found any institutional resistance at all.

Participant-I That said, the support for teaching I feel is great and so much so that I am, myself, not worried about that part of going up for reappointment, that part of going up for tenure. Because, I'm getting a lot of support and I'm also getting feedback. I'm less concerned about that.

Participant-B I did this long after I was tenured. I used to ask myself, "I'm tenured. Why am I doing this?" There's really no good reason in terms of return to me. It was because I thought it was important to not fail 10 to 15 % of the students.

Participant-I I don't think I'm ever gonna implement them on my own, at least until post-tenure, right? At least until I'm not trying to do other stuff as well and have some freedom to screw up.

Participant-Q I also keep track of that for my tenure package of like things that I'm adding and how that's going and all of that.

Participant-E I started the Physics Education Research literature, and wrote what I call my physics manifesto, which is up on the web if you want to find it. And basically lying out of plan for how we would transform the introductory courses in our department, and I [Inaudible] to an NSF proposal, which was funded, and so they launched that project.

Practical consideration

Participant-Q I feel like I have enough time in the day to really think critically about how I'm developing my course.

Participant-Q But, we do actually have the, I would call it, bandwidth to think critically about how we teach our courses. I mean, like I said, I only have two sections of students and there's only 20 students each in those sections.

Participant-S Those are courses that I have experimented with and made changes with. This is only my second time teaching the circuits course, so I have not made any changes.

Participant-C I wanted to try one of those methods, and particularly the ABCD cards seemed to be very simple. There was no complicated ... you know, I didn't have to take my smartphone out and do anything like that.

Participant-D This is something that I thought I could implement very easily. Without changing much of the structure of my course.

Participant-B I tell the students that this a terrible way to teach, but it takes too much work for me to be interactive. I do use Clickers, but lecturing is the easy way out. I don't think it's particularly effective, but I've got a lot of other things going on, and I've done by duty as far as my institution education goes.

Participant-N So, she has the teaching assistants, because we don't have a learning assistant program yet. Hopefully, teaching assistants help with the lecture and so she's trying to scale it up for the lecture class.

Participant-B I had a lot of money. I had people who worked for me as post-docs to produce material.

Participant-G So, we had kind of good materials to start with and a lot of people willing to share and take with us (start with Nexus and go from there.)

Participant-G She had worked with me as an LA in other courses, who was highly motivated and wanted to get into PER. And so actually, she's now a PER student at Maryland. So she was highly motivated and was willing to work on the team to kind of do these reforms.

Participant-W Bringing innovation with this sized class, bringing in things that I would like to do more, that would involve more student engagement is problematic.

Participant-G The Physics Department, we were struggling with some of our space for labs, and so we thought, "Hey, this is a great opportunity and this is the perfect lab to move in there because it's interdisciplinary already. It's a physics lab but it's not for physics students." So there was that kind of motivator, that we had space. There was an opportunity to use it, and if we're gonna be basically moving and buying new stuff, this is the right time to reform.

Participant-J Having the planetarium is inspirational to me in some regards, thinking about how to teach.

Participant-J I teach in this really big, this great classroom. I'm in this new building, and they've got all these tables that you can roll away and stuff.

Participant-G We also have to realize that we have a practical constraint, which is we have people who are not super well trained facilitating.

Participant-C Initially, I thought that, Maybe I should do all of these, and then I realized even when I started doing one of these, it's a lot of work and it's a lot of nervousness that goes into it.

Participant-M I'm thinking to do something a little bit about the phases of the moon too. I was going to do it this year, but I didn't. I didn't have time. It's always easier just to go with what you've previously done when you're busy.

Participant-A I like to get them up and I like to get them engaged and I like to do stuff in the room with them, but it takes time.

Participant-I It requires a lot of time that at the moment I don't feel I have.

Participant-N I don't have enough time to modify the rubric and all the stuff and I was discussing with my TAs. One of them has TA'd for me before with this activity and he's like. All this sounds complicated.

Participant-E People stick to the lectures: because the amount of prep time outside of class is much lower than it would be in a traditional setting. The lectures are now scripted, so you're added. Here's the slide deck. You can tweak it if you want, but you don't have to start from scratch.

Participant-I I'm more worried to make sure that I can still publish and that I can make tenure because that's more on my worry. I'm less concerned about the teaching.

Participant-I So, I want to be able to use those whiteboards, but it doesn't work at all because the whiteboards are 3-feet by 2-feet and when your desk is 8-inches by 9-inches, those whiteboards aren't a valid option for us.

Participant-I But, the classroom is just a blank room with movable desks that look like high school desks. They've got the little, it's a chair with a little desk attached to them. And the room is shared with many departments and I think there's a Spanish class that uses it that always puts all the chairs into a circle. And that's not always the most helpful thing, so there's always a little bit of making sure that people can get to desks and moving that.

Participant-A And some of that I think not every student brings a computer to class, and we don't have computers in the classroom. If I was thinking far enough ahead I would say, "Bring your computers tomorrow," or "Bring your computers on Friday because we're gonna do this." And I haven't been thinking that far ahead.

Participant-W It costs zero money.

Participant-C Haven't tried to use them, specifically because it also increases the burden of the students having a Clicker. If they don't already have it, they have to go buy it, so I didn't want to have that burden on them. But in different ways, I've seen this method.

Participant-B B. G. gave my institution 25$ million, so there was 35$ million floating around in 2000 for education, specifically for education.

C.3.3 What resources physics instructors use related to new ideas::

Online resources

Participant-C I have also looked at the ComPADRE website sometimes. I use that mostly for my upper level classes, quantum mechanics and [Inaudible] no problems with it.

Participant-C I might go to the ComPADRE website to see if there are problems that people have specifically talked about.

Participant-J I think, I follow astronomy blogs, and that's where I get a lot of my current information.

Participant-H Super thrilled that PERbites became a thing.

Participant-H I've been reading Astrobites for a long time. I don't know how long they've been around. But, I've been reading Astrobites for a while.

Participant-C Because, I know most of my students access it and I tell my students, hey, you know, if there's an online resource that you like, please use it, there's nothing wrong with, you live in the era of technology.

Participant-D I think my institution physics course, they have a lot of nice videos. Content monkey demo, I use that, their video actually.

Participant-N A lot of times I'll use videos. My institution Tech TV physics demonstrations, I like a lot of those.

Participant-S The resources that I got from Colorado are only for the first half of the semester because they do a combined mechanics and math methods course and they only have the first semester online.

Participant-F Those seem to be really, really helpful for folks to demonstrate stuff and put into their presentations. That's one great resource.

Participant-P So, the last one we did actually was on the phET energy bands simulation. And it was after we had nearly free electron model, before we did a linear combination of atomic orbital type thing. And that one is evolved a bit through like, this is my second or third time. It's my third trying to use the PhET, second time trying to do with an activity.

Participant-D Like when teaching special relativity for instance where there is not many demos you can do in class. So there I can use some animations. Yeah the PhET.

Participant-C YouTube and try to look up fun activity videos and try to see if we can put physics in it.

Participant-J I pick things up from different YouTube videos I watch, I guess. I get inspired.

Participant-P Has used the PhyPort for intro course, and advanced mechanics.

Participant-H I do go and search through Physport every now and then. Mostly to check up on recent research, or if I hear about somebody who's working on something interesting, and go and look at what other things they've published.

Participant-G Have been kind of browsing on FIS Port to figure out what assessments might be useful for these labs that we're creating.

Participant-D Also Flip It Physics has some slides available. So I use that as well. And they have a very nice collection of Clicker questions.

Participant-L When I have made time to do the FCI pre and post, my hate gain is as good as or better than active learning across the country.

Participant-O That's been really helpful. I keep waiting for the IPLS folks to get their website going. I'm looking forward to downloading all sorts of stuff from there and getting new ideas about how to teach more bio-related things. All my students are interested in that, and I really don't have a great background in that.

Participant-G Portal I use things like I'm desperate for this IPLS portal, this living physics portal to finally start. So that we can start to use that.

Participant-M There's a couple of labs that involve the planets where celesta They read about them and make sketches, and do somethings on the computer about the planets; that's are labs.

Participant-U For example online resources that we have so Compass or Moodle all these things that I am still learning how that works.

Participant-B Well, there's a lot of visualizations in it. We had some very nice Java 3D applets.

Participant-A I like to use a lot of applets, online applets and tutorials and things like that.

Participant-L I think if I were to find an email list server or something that's good new ideas in science-ed or physics-ed that I could be a part of. That might be good, 'cause I would especially be paying attention.

Participant-T I got an email. Oh, I was on this list serve for like lab instructors, and I think, yeah. There was an email thread.

Textbook-related resources

Participant-P I started with the Oxford Solid State Basics, was the book I taught out of the first two times. And the second, then I switched to Kittel.

Participant-P So I've tried to pull from a lot of textbooks sort of things.

Participant-J I use this textbook by Comins and Kaufmann, it's called Discovering the Universe. It's fine. It has a digital version, and so it has a digital homework thing, like Web Assign, but it's built into the textbook.

Participant-R I looked at textbooks, which, for example, [Inaudible] there's a classic introductory physics textbook.

Participant-W So we developed a worksheet for it that's students had to work with.

Participant-U I mean there are some books and I like those books that they have some conceptual questions, and then they have the problems.

Participant-U Different books, and just think about the actual examples and try to think about if I could go and develop something further and that it's to the level, or something that I've been using in the past is trying to relate movie scenes with things that we are studying.

Participant-B We had a big demo group, which would do demos in the big lecture courses.

Participant-J I highly recommend Universe Simulator Two. No, sorry, Sandbox, Universe Sandbox Two.

Participant-K I've actually pulled Clicker questions from there. So instead of giving them the worksheet and giving them like 20 minutes to work through it, I just throw one of them up there.

Participant-P Do the odd activity or worksheet that I've tried to make.

Participant-K We're also using Mastering Physics for the homeworks. So there's quite a lot of things in terms of the raw materials.

Participant-U I was talking to faculty here that, Professor that had been teaching this before and gave me some examples on problem sets, exercises that he developed. I mean outside the typical problems that you can find in any textbook like some numerical problems, how to solve them excel or with Math Lab or things like that. So some ideas that he had developed which I am also implementing, but not enough about this pre-class activities or no.

Participant-C Usually what I do is I look up questions. I do have question banks earlier from my colleagues.

Participant-U So, the person that had taught that course previously just met with me and just showed me everything that she had and how she was doing it, and that anything that I needed just that she was there to help. And she just gave me all those tools and I really, going over them I really liked them. So yeah they were very supportive.

Participant-S The professor who was at other university, he's got a website that you can go to that has some activities.

Participant-S We had a faculty member who taught at [Inaudible] and so he had a bunch of tutorials all designed for Griffiths, of course.

Participant-D Actually after attending this new faculty workshop. Where I learned about the just in teaching methods. I thought it was really nice because we can get active feedback from the students immediately.

Books/materials about how to teach

Participant-A Every now and then I'll read an article from the Physics Teacher or whatever it is, something from the [Inaudible] or find something online or from Physics Today.

Participant-E I spent a semester. I had a fellowship spend their semester studying all of the literature. So just looking at what do people know, and what model to be successful and adopt that.

Participant-L I feel like I read occasionally when I have time, honestly it's mostly summer.

Participant-L I don't really read up on what's being published in the Physics Teacher, or the American Journal of Physics as much.

Participant-I I should probably read the article again, but it was probably AJP had a PER thing that had something there. And so they had this idea of consensus building that

I really enjoyed. So I've implemented that and I have found, in my opinion, positive response from it in that I get more discussion in the Pair-Share part and I get more people changing answers.

Participant-T I guess I go on the American Journal of Physics and America Physics teachers website. And like I would browse and see what people are doing.

Participant-R I have relied on journal papers.

Participant-I This one might have actually come from AJP. I might have read AJP now no longer publishes physics education research, that was one of the things. But I think I might have read something where they had this idea of consensus building, because I personal goal of mine, and this is something I need to try and do, is for the Physics for the Life Science I am less concerned about their learning the material and more concerned about thinking scientifically.

Participant-I I'm an AAPT member and so I love my little yellow magazines. They're my absolute favorites. So, I get those regularly and I peruse them. It's once a month and so it's easy. Now that there's no longer PER [Inaudible] behind, but for a while it was pretty nice.

Participant-O Arnold Arons had a great book, so I had that book and used that. J. R. and some other folks came out with a nice book, Teaching Physics with a Physics Suite, or something like that. Maybe you were involved in some of these things.

Participant-D So, we use this book Physics for Scientists and Engineers, Randall Knight. And that book has a lot of resources available online for instructors.

Participant-K I've got text books, you can probably see a couple of them behind me of all the other books that I've used in teaching. Berkeley uses Giancoli. We use Wolfson here.

Participant-K Five Easy Lessons, Strategies for Successful Physics Teaching, by Randall Knight.

Participant-G I mean like all the resources which I got way back at the AAPT workshop, I still have. You know, like Eric [Inaudible] book, so over there somewhere. I can see the tutorials, my tutorials book over there. An also, I haven't read it cover to cover, but I'm familiar with the, I think, it's the NRC's Deber Report.

C.3.4 How physics instructors find resources

Talking to other people

Participant-P Like I have family members who teach high school and that. But, we don't really get into much of the nuts and bolts.

Participant-L He keeps up with stuff so much better than I do and so obviously any time he comes up with something new and he sends it to me then that's fun, looking at general science education things. General things about new research in cognitive science, not really specific to physics education research.

Participant-B My wife I talk to about teaching, but that's mostly it.

Participant-S We have a faculty member, she was just hired a couple of years ago who has a PER background. I'll ask her and see if she can send me somewhere.

Participant-J I mean I have some friends who are really big into Physics Education Research, and so I'm definitely not,... I just sort of gleaned things.

Participant-E They'll come and ask either me or some of the PER people saying, "Where can I find materials on quantum mechanics?" We point them, say, to groups that we know about, or if we're really smart, we point them to ComPADRE in the spot in that whole online thing. And then how they're going to use them, they'll think about it themselves, look at them, maybe come talk to somebody with expertise, and go back and forth, and maybe just try it, see if it works and that sort of thing.

Participant-O The MOOC was built with a few high school physics teachers and also a teacher in residence. That was kind of collaborative. There's a teacher in residence, actually. He's been with us now for six years.

Participant-O We've got a set of courses for high school physics teachers at BU that I was involved with a few years ago. The design of, but also the teaching of. It's been interesting to interact with the teachers from high school. They have some great stuff going on. It's fun to talk to those people every once in a while, and take ideas from them. We have meetings on campus, physics teachers, every once in a while. Usually four or five a year. They come and show off demos and things like that. It's a fun environment.

Participant-O His colleague, Manher. He has great ideas. He's doing the calculus-based intro course and I'm heading up the algebra, but there's a lot of overlap there and we work together a lot. He's fantastic to work with. Also He's actually heavily involved in the LA program, he is training his LAs. We talk a lot about how to use the LA's most effectively.

Participant-U Talking with other people.

Participant-Q Especially, here at the my department, there's a good percentage of professors that have some interest in exercising kind of novel ideas in terms of how they approach teaching.

Participant-U Hadn't taught before and they just gave me, I mean all, a lot of material on how the previous faculty was doing that and I could use it or not, as I wished. But I really liked the idea of having the students warm up before coming to class and they were very well thought, those activities and everything. So, that, I did that the first year, and then I continued doing that the second year and I tried to implement in other courses that hadn't those activities.

Participant-W I would say one of my greatest inspirations are my colleagues working and sharing idea all the time.

Participant-C The problem-based learnings, I have taken a lot of material from him, and we have sort of talked to each other and developed material together. And then we have another senior faculty member who we talk to a lot. So, the three of us do communicate a lot.

Participant-C One of my colleagues and I are pretty close, like, pretty much every day we would just talk about these problems when we are, let's say, having lunch.

Participant-D Yeah we have the demonstrator, the assistant that helps us with the demos. Like setting up the demos and explaining to us all the things about the demos which we'll be doing. So he's a great resource person I would say.

Participant-Q There's another professor who started at the same time as me and when I was developing these course materials, I would check in with him all the time. Mostly because we were sort of just both going through the stuff for the first time. Also, because I felt more comfortable asking him stupid questions.

Participant-D And then we have the lab coordinator, see also sometimes, tells us nice tapes, like this is something that's coming up in the lab, so maybe you could add a Clicker question, something, like related to that, for instance.

Participant-Q I've been going to these meetings weekly for whatever it is, the past two years, going on three years, now. And so, I see myself maybe contributing more than I gain from those meetings. But, it's still, I think, for me, in terms of gauging where I'm at, engaging with the new professors, helping them in whatever way I can, 'cause I found those meetings super helpful when I started, and so, like sort of whatever I can do to contribute to that, I usually try to do. And so, yeah, part of it is like making the new professors feel comfortable in teaching this course.

Participant-Q There's a couple of folks here that have been making videos for their courses and I've talked a lot with them.

Participant-Q There's one other professor that, he started like a year or two earlier than me, but, his research is pretty similar to mine. And so, I talk with him pretty much on a daily basis, just like checking in how things are going. He's in a different department than me, so, it's sort of an easy way, low stakes person to talk to that I don't necessarily feel like I'm in any ways being judged on my productivity or ability, but, just have somebody to bounce ideas off of.

Participant-Q So, yeah, part of it is selfish and I gain a lot out of these conversations and I learn a lot of new tricks and I develop ideas as I'm talking about them. But then, also, I think a big part of it is I realize that like to have a healthy community, you need to be part of a healthy community. So, that's something that I try to engage in as much as possible.

Participant-Q I probably should read more. But, I gain most of the sort of skills that I've developed in teaching, I think, from interacting with people.

Participant-N The three of us (lecturers) meet every other week for lunch to talk about what we're doing in our classes and what's going on and stuff.

Participant-Q Another professor- he put out a sort of call as to other professors that are interested in making videos and then, we kind of went from there as to putting together this like video library.

Participant-F Because, those two guys are focused on physics pedagogy, we get a lot from them in attending meetings and events that they hold, and they're always sharing them with us.

Participant-B We would have weekly meetings. Each faculty member would have also a meeting of the people who were helping him teach, and that could be up to five people and his graduate students and his undergraduate students helping him. They generally were not well attended. That's just a fact of life here.

Participant-I I've got two other nontenured professors here that I converse a lot with.

Participant-I There are three of our very experienced faculty that I talk to a little bit. It's harder. They're my bosses in a sense. I mean, one of them's the chair, right, so that's not just in a sense, they are my boss. But the other two are experienced and even if they're not current chair they may be the next chair because the way the chair in these small departments.

Participant-I I can talk to him about stuff and one of the things that we're discussing, that again I'm not gonna implement until after I get scholarship and other stuff done, is he does some stuff in his class that implements improve ideas, ideas from improve theater, that I just think are wonderful and can we get more interactive in physics classes doing the same type of thing. I don't know, because, we have a much more specific goal a lot of times than they do in English classes. But still, I really liked it.

Participant-H I spend a lot of time talking about teaching in general with the rest of the ... with the other folks how are teaching these lower division intro courses. I'm kind of in an office pod here, where four people are sharing a couple of rooms. And, all four of us teach intro level physics. So, we're always talking about ... We're running into each other all the time and just having casual office conversations about, "Oh, what are you on?" and that sort of thing.

Participant-I I would actually not just like go and observe an individual class, I would go and sit in and watch them teach multiple classes. Because an individual class is not as helpful as a set of four. You see how they chain one idea to the other and, yeah, I would absolutely do that.

Participant-I Then the other thing, I actually have a fairly good interaction with another of my cohorts. So he's also in his second year here at Union in the English Department, and we've actually sat in on each other's classes. I can talk to him about stuff and one of the things that we're discussing, that again I'm not gonna implement until after I get scholarship and other stuff done.

Participant-H We have a pretty active Biology Education Research group on campus. So, I'm involved with them. I'll go talk to them.

Participant-G Whole instructional team meets with me once a week for about an hour and a half to debrief on the previous week and to prep for the following week.

Participant-G I mentioned here, C. D., she's definitely a resource and a great thinking and working partner and collaborator.

Participant-D So, we also have actually a teaching mentor. That's what I was going to tell next. So he comes to my class, and then he sits in my class, and he gives me tips. Like last year he did once, and then I went to one of his classes, to observe how he teaches. And he's teaching a much bigger class. It's like 250 students. He's in science and psychology. Yes the content is different, the class structure is slightly different, but I try to learn how he's interacting with his class. And then I try to kind of follow some of his suggestions and advice.

Participant-V We talk about things like this a little bit in department meetings. It's a small department. There's only three full-time faculty. We talk about these things a little bit.

Participant-V Support group or some people I talk to, it's like support.

Participant-E I am the chair of the foreman education. We talk about what are ways that we can help more people understand how they can transform their own teaching to make it better.

Participant-E The other people within the course that I'm teaching, and with our PER people. I also co-teach. Right now, this semester I co-teach in class on physic and music, and I co-teach that with a professor at other department.

Participant-K We meet about every two weeks or so as a group and say, okay, this is the next lab.

Participant-K There's K.H., who used to be the director of that center of physics education research, so now it's moved on to someone else. She's working in the laser lab. If I ever have a philosophy question about teaching I usually go and talk to her.

Participant-K There's a gentleman who's been here for quite a while, another pilot that's retired and came back as a teacher. He's actually retiring next May, so that'll be a big hole in the department. He's like Mr. E and M. He knows everything about electromagnetism. If I ever have a question about, "How do you teach that?", and he says, "Oh, I do the paw law." I go, What?

Participant-A Every Friday she did a journal club where she would have five different professional articles about the role of estrogen and breast cancer, something like this and the students were broken into groups and they had time to prepare the day before or whatever and they had to present the findings and kind of argue and debate because they didn't always agree. So that's something I look forward to doing when I have upper division classes more to be able to do something like that. I don't feel that I have the time to do that in the lower division, but you know, stealing as many ideas as I can from faculty that I know. That helps too.

Participant-P I'm really fortunate here, because we're small department of six, tenure track faculty. Two of them are PER researchers, they're kind of a [Inaudible]. So, I annoy them a lot with just walking down the hall. Pass some time just venting, being like I don't know what to do. And other times like, genuine questions about like specific things. So I have a lot of peer conversations I guess, about different techniques.

Participant-R I have talked to others and I have observed how they teach. But then also, the courses they teach have totally a different context altogether. For example, they teach with courses which are very well defined ... I mean, some of them teach ... let's say statistical physics. So the content can be found in several standard textbooks. And then you can focus on delivering the content very well.

Participant-J Then he's an expert on making posters. And so I had him come in and talk about how to make a poster. And then he was trying to get them to interact with him in a little bit different way than I had. And I thought that worked well. So that wasn't me observing him in his class, that was him talking to my students. But I have been observed a lot, like countless times. It's really worn down my fear of being observed.

Participant-S I think I mostly just sort of talk to trusted colleagues in the department. Yeah, I don't venture far outside of the department. I don't go to the other sciences or anything like that. Sometimes, but not much. I guess I feel like at our Physics Department is trying to do more and change more rapidly than the other sciences, certainly faster than chemistry. So, I end up being pretty insular.

Participant-B I went down to B. B.'s operation, and we sat in on SCALE-UP and talked to B.

Participant-J I'm up for my two year review, for my tenure process, so I've had a bunch of colleagues observe me. So people who are from my department observe me, and then I've had other people from sciences, and then people from humanities also. Because whoever is writing letters from my tenure file. And then I've gotten various degrees of feedback from them, some of which has been formal, and some which has been informal. And some of them haven't said anything, so I [Inaudible].

Participant-B I had had some interaction with B. B. at other university.

Participant-B J. D. was a big influence on me. She's an educator at other university.

Participant-G I won was not money but was sort of like an entree into this community and so we meet every year. and there's a conference in the summer.

Participant-G Talk to former colleague of mine, B. S., who is now the chair at other university. We were willing to kind of take risks together when nobody else really cared.

Participant-G So, she was trained as a TA. So, she was very familiar with context-rich cooperative group problem solving, and she's totally bought in on that.

Participant-P I was fortunate enough to meet a professor from other university, at the New Faculty Workshop. Who is in the exact same position I'm in. Where they're teaching that. So, we actually and we're in the faculty online learning community together as well. So, we paired up a lot and like I know we've both used like those activity worksheets. Like I've ran them by her, and she's sent me something that she's working on. So, we use that resource.

Participant-I The Think-Pair-Share initially, just like implementing something, came from just recommendations at Lawrence from other professors and so I did those.

Participant-I That's something that I have done at Lawrence, I've sat in on multiple classes in a row, which is again, really cool and useful.

Participant-T I guess we were applying to this grant. I guess that's where, like M. J.'s come in. So, he's the consultant for undergraduate research council, or whatever their name is. So, that's sort of the first time I really talked to people that, you know, outside my department about curricular changes.

Participant-A Other teachers. I've got a friend that I went to grad school with, he spends all of his time thinking about this kind of stuff. It's been a little while since he and I have talked now that I'm out here, but we would talk about this constantly. And he also was a student of the paradigms and a TA of the paradigms so we had a lot of the same background and we drew from the same references anyway. We had a lot of the same questions and the same desires to be good teachers. He's probably one of the ones that I pulled from the most.

Participant-R I did contact some people who have successfully implemented these experiments.

Participant-T So, that's sort of the first time I really talked to people that, you know, outside my department about curricular changes. So actually, it been fairly helpful to me to sort of get me up to speed with things and seeing how different places, how different Physics Departments work. And I mean, we also invited C. W. to talk last spring. And then after C. W. came to talk, I decided that I really need to talk to someone that did the more of the physical work. So, I invited N. H. to come to talk.

Participant-J We actually have a visitor right now who is an expert in PER, so he has feedback, and he's taught some astronomy before, so those things all ... So, for instance, he taught me, he gave me some good advice about how to talk about the different ways the planets move across the sky at different speeds than starts do, and that sort of stuff.

Participant-S I'll talk to people at conferences, like other physicists of conferences.

Attending to workshops, conferences, community, seminars, departmental colloquiums, reading group

Participant-Q A lot of it came from the AAPT new faculty workshop meeting.

Participant-O I think I would have to say the AAPT conferences would be a big one. I enjoy going to ... I used to go to both those annual meetings each year and I always get something out of that. There was always people doing interesting things and you could go, "Hey, that's really cool. I can do something along those lines, or I can try that too." I really like those a lot.

Participant-T I never felt that the national meetings would be very helpful.

Participant-G I think the other thing is the AAPT community, of course. I think that's one that I started to tap into more. Locally, it's always been kind of interesting.

Participant-I For institutional support for teaching I'm finding great institutional support. I have been sent to the New Faculty Workshop. I was sent to a, they called it BUFFY, Beyond the First Year. There's also an AAPT, I guess New Faculty Workshop is AAPT and APS, but the AAPT also does a Beyond the First Year lab thing. I've been sent to that. Very positive experience.

Participant-U Well there are some workshops that- and they are very focused on new faculty that are going to be starting in a couple weeks and I will be attending them.

Participant-U Just to know what people do and how it works for them and see if that will fit into my teaching or not.

Participant-D Actually after attending this new faculty workshop. Where I learned about the just in teaching methods. And I thought it was really nice because we can get active feedback from the students immediately.

Participant-Q Definitely the AAPT workshop was one that I was sort of like very happy to see myself gaining something out of.

Participant-I I was most excited about and I talked to people here and we have whiteboards and they talked about stuff that worked and then I go to this room and the room does not even slightly use.

Participant-I That when you implement something explain why you're implementing it and the goals of it, and I have found that when I try and do that, the main thing I get from the students is, why are you talking about teaching and not teaching. Does that make sense?

Participant-G I went there I was a young faculty member. So that was a formative experience for me.

Participant-P As ya know motivated by the folk workshop or anything.

Participant-P So, I did the new faculty workshop in the FOLC. And those were both, I would think extremely useful. And those were both, I would think extremely useful.

Participant-S I see somebody doing this or I hear somebody doing this if I go to a conference and then I say, "Oh, that sounds neat," and then I'll try it. I'm less of a ... Not even less. I'm not a search it out and read how to do this and then try and incorporate it in my class. I'll sort of go forward and then if I learn something new I will incorporate it, but the learning is not an active search on my part. It's a passive discovery and then,"Oh, can I find out more about that?" But it's usually in a conversation, like can I find out more about how you did that. Or I'll be in a conference in somebody's talking about something and I'll ask more about that. But I don't go to the PER conferences. Where I've done that is more of the advanced lab conferences. I've been to three of those, two of those.

Participant-C Now, I have attended some of them, and there has been interesting discussion about what is good in your class and how to manage certain things. But I'm not sure that has been extremely useful for me.

Participant-O There is a center for teaching and learning and they do sponsor teaching events, teaching talks. They do have these little grant programs that happen as well. They're trying to do stuff like get small groups of professors together just to talk about various teaching issues as well. There's some of that at the university level for sure.

Participant-D So, in our teaching center, I sometimes go to one of these training classes, And they gave us a book, Teaching at it's Best. And I forgot the author's name. So I took some tips from that book. And also the teaching center workshops are also useful. So I try to use some of their techniques as well.

Participant-Q We also have a Center for Teaching and Learning here that I've ... And that's another place that I've learned about a lot of these techniques or thought about, had conversations about a lot of these techniques, is various workshops at the Center for Teaching and Learning.

Participant-N We do have a learning center. The CETL, Center for Engaged Teaching and Learning is very cool, really opened to ideas, great to talk to. I just don't run into him very much.

Participant-G Our center for teaching and learning is not awesome. I'm not getting anything new, generally speaking.

Participant-V I guess they kind of lead the charge on initiatives like the CETL, the Center for Excellence in Teaching and Learning. They send out emails. They have other things they do, different workshops.

Participant-T There were a talk at our center of teaching excellence set up. It was the guy. I don't remember. It was a book called Discussions as a Way of Teaching. It was one of the two author, I don't remember it was Brookfield or Prescott. But one of them came. And he gave I guess like a three or four hours workshop. And he didn't talk specifically about doing those things, because I think the speaker came from a school of education background.

Participant-K There's that, we have a center for learning and education here that we have these seminars all the time that are innovation and whatever.

Participant-A It's the Center for Teaching and Education Learning or Excellence and Learning or something like that. We have a department on campus that is all about helping faculty across the departments to kind of be empowered for engaging students and doing active learning and pulling technology into the classroom, and a lot of the stuff that's been going on in PER for years, they've got this department that does a lot of that. They've been a resource that I've pulled on a little bit. They have workshops all the time and I've gone to a couple of those and I'll go to a few more and they're actually, I got a grant to help pay for my travel to this conference through them, so that's good support. Yeah, that's another resource that I pulled from.

Participant-B We also went off to a summer workshop that was given by K. C., who was then at ... Where does studio physics start? There's a fable beginning of studio physics. I forget the name of the guy, but K. C. was the faculty member there who was carrying it out at the point. She's now at the University of C.

Participant-H I don't think I would've found the ranking tasks if I wasn't so used to using the lecture tutorials. And, I found out a lot about those by attending the old Cosmos in the classroom conference that was put on by the Astronomical Society of the Pacific.

Participant-P When we're in the FOLC, this was the class I was planning on using that, they had like a project you were supposed to try to do. So I was trying to redesign this course a bit, and see if I could figure out how to do that.

Participant-M There is conferences by the professional development, the PVP from easy S. C. that I attended. That's where I learned inquiry during the years to make it more.

Participant-H We'll have ... the weekly speaker will be doing education research topics. I also try to go to some of those sorts of talks that are hosted in other departments.

Participant-V There was just one recently on, so we have an office of accessibility resources, so that's like disability resources, same thing; just got renamed.

Participant-E I'm part of the faculty workshop committee. I give a plenary there. I work with them about how do we help people who are new to faculty positions? How do we help them get started on their teaching them this way? Yeah, a lot of people in national conversation [Inaudible].

Participant-S So, we tend to have at least one or two PER speakers per year. And so they'll come in and talk about that sort of thing. Otherwise, it just happens to be in conversations about classes or teaching or that sort of thing.

Participant-H We usually have a science education colloquium. Once, or maybe twice, a semester.

Participant-H I also think a lot about what students need by having conversations with other faculty who are outside of my department. So, I'm part of a couple of reading groups. One is focused on social justice and institutional change. And, I meet with them every other week. And, we talk about, "What do our science major students need? And, what sorts of experiences do we want students in our college to have around science?" So, that informs a large amount of my teaching.

Participant-V On campus, there's a reading group I'm a part of for improving teaching. It's colleagues from across disciplines, a huge variety of disciplines but they're still... the group I'm in has people from all across campus but I think we talk and that's one of the ideas I was seeing, was try to reduce the lecturing time.

Participant-R The only formal way I had tried to develop this course fellow in the faculty learning community where myself and a person who is teaching computer engineering, software development.

Participant-C But right now, I am also part of this faculty online learning community, which started at the [Inaudible]. So, I'm talking to them sometimes. We have a [Inaudible] we talk to each other once in a while. So, they have been helpful. People have come up with questions and stuff like that.

Google and twitter

Participant-W I look up stuff online all the time, but most of all, I try to just find physics in my everyday experiences

Participant-I The first was I watched, and this was probably right when I started my teaching at my University I watched a How to Teach for Science and Engineers videos. I'm trying to remember the name of the professor, but it was a professor at other university that taught it and he had these minute papers and what I saw happening is I saw him addressing the questions in front of the class. I absolutely loved that. I thought that was great.

Participant-W Seeing physics everywhere and examples that I could use to illustrate things for my students, and then I go onto the internet and look for resources like videos and other things that I can use to illustrate the lectures.I use lots of videos, lots of simulations, all kinds of stuff like that to enhance the content.

Participant-I In addition I avidly follow a lot of YouTube science educators and so I think it was PBS Space Time does this, and PBS Space Time at the end of every video, they address comments that had been made on the last video and they address them individually.

Participant-A I've been teaching physics, this one in particular long enough that I kind of know how I want to approach the class or what I might want to do differently day by day. If I'm looking for something like that to mix it up I'll either go to something I know or if it's an applet I haven't used before I'll just Google and see what I find.

Participant-C I will probably use Google search.

Participant-T If I have a certain like concept that I think I don't really have the best way of just explaining it, so I would do a Google search, and a lot of time I would look for like articles in the American Journal of Physics and see what people have thought about previously about this particular idea. Like, you know, like capacitance.

Participant-D I just, yeah it's kind of just, Googled around.

Participant-M Searched the internet all the time, to just get up to speed about the latest news that is happening in astronomy.

Participant-C I will probably use Google search.

Participant-V That makes sense. When you currently are looking for demos, are you just typing it into Google? Yeah, that's pretty much it or I just go into the lab, the intro lab, I'll just go in and see what we have piled up and try to piece something together.

Participant-O One thing I would say is Twitter a little bit. I follow some interesting physics people on Twitter.

Individual inspiration

Participant-P It came to me in a dream. So I'll think, a lot of the time.

Participant-J Anyway, I don't know. I just sit around and think about these things sometimes. It's usually when I'm taking a shower, or when I'm falling asleep or something.

Participant-U I mean this video thing just- I just came up, I mean I guess I'm not the only one. I mean, there are maybe hundreds of people working with that, but I don't know I like that and I develop that.

Participant-U Well, I like science fiction and see lots of science fiction. So I use clips in classrooms so I show them a little clip and then talk about the physics.

Participant-A I took a shower. You know, I teach at 9:00 AM, I start thinking about class honestly when I get up in the morning like what am I gonna do today. I don't know, that's just it.

C.3.5 Resources physics instructors would like to have

Teaching materials

Participant-V It's never one website, it's the spot for... or maybe I haven't found one. Although, I did see, I got the SPS mailing and there's some free demo kit that you can ask for if you're the SPS club. I think that's something. I don't know if the students have looked into that. I would like to have a nice, big list of inexpensive demos. I can find it anyway, it just takes a little more time I guess.

Participant-C I mean, I don't know if you know about compendium of intro physics questions, but I could just go and look up. But, that's probably the thing that I'm looking for. I'm trying to make it myself, for future class.

Participant-A The other thing they did for biology, I haven't seen it as much for physics was they had a really good bit where they had current events in biology where students would read articles and then have to answer questions about it. I haven't seen that for the physics yet, that doesn't mean it's not there, but that was something else that was nice to draw from.

Participant-A I've been wanting something a little bit more interactive in terms of essentially like a website that's got a code written in the background where you can actually enter in a bunch of data and have it generate a chart output or something like that that is ... how do you say it? Something that doesn't crash, something that works.

Participant-M I would want a website that has really good animations or simulations of difficult concepts, like reason why have the seasons, the phases of the moon, all in one website.

Participant-J I think having banks of good questions that are not publicly available.

Participant-L I feel like I pay attention to things if they show up in my inbox, so I really should be signing up for a digest, even if I don't read everything.

Participant-H This semester I was like, dang it. I want, ... I would love, more than anything, to have the lecture tutorials for Intro-Astronomy, but for physics.

Participant-I It's how I interpreted it. I don't know if that's the proper interpretation. Again, maybe a little bit of training on how to do some of these things.

Participant-E It would be nice if there were sort of the PER jar. Just some sort of handbook guide book that basically said, here are the important things that you should be doing in a class. Of course, for anything like active engagement, there is a lot of different ways to do it. But basically saying, Okay, to be effective, you need have to have this characteristic in your classroom. Here is five ways to do that, and this characteristic.

Participant-S A repository of places where I see how other people have approached sort of the whole course.

Participant-C Would be useful is to have some guidelines for what to do if it's a complete failure or success.

Participant-A But, I've been wanting something a little bit more interactive in terms of essentially like a website that's got a code written in the background where you can actually enter in a bunch of data and have it generate a chart output or something like that that is ... how do you say it? Something that doesn't crash, something that works.

Participant-P All of the stuff there is for 201, for Solids, or the Introductory for Solid State.

Participant-I The other thing is there are very few attitude assessments. The class surveys tend to be a really good one and maybe that's why they don't have anymore. If you go and look it's like platinum star or whatever, it's got all these things. But, I couldn't implement it, and I tried to find another one and I didn't find other attitude surveys that fit the bill. They're like attitudes and electronics, and attitudes in experimental classes, none of which were what I wanted. I want this general scientific attitude and I couldn't find others to fit the bill.

Tools

Participant-U They initially they looked very shy and they just get the paper and work on the paper. Then one thing that I did in the past is- two or three have a whiteboard and I don't allow them to use any paper, just one marker and one whiteboard. So, the two or three have to work in the same whiteboard. So, then they start to discuss the stuff between themselves. That's why I have that in mind, that probably going back to the whiteboards would be helpful, just to stimulate discussion among them.

People support

Participant-T I think it would be are helpful to be able to have someone objective and not, you know, giving me a grade for like ... you know, you know, the person not reporting to the chair or the Dean's office, just someone that have a background in education and understands the challenges in teaching sciences, like STEM related subject, and just sit through a couple of my class and just tell me what I'm doing right, what I'm doing wrong, how I could improve. But, there isn't really anything like that here.

Participant-T We don't really have anyone in the hard science. I mean, I'm not saying they have to be a physicist, but you know, like a chemist or even a biologist could sit in and just comment on how I'm teaching.

Participant-R I didn't discuss formally with anybody, anyone from the education department or the physics education group, nothing. It was mostly self-planned.

Participant-C What would be useful is to have some guidelines for what to do if it's a complete failure, right? So, for instance, the one that didn't work for me was that the boards that I was talking about. And I got super nervous, and so I didn't do it again. But it doesn't mean that that's not a useful method. So, you know, if there was some discussion somewhere where people could share ideas and talk about what they did, if it failed, for future [Inaudible].And, yeah, I think that would be very good support, if that happened, to be able to talk to other people who may have implemented it and seen either success or failure. Beause it doesn't matter whether it's success or failure. Knowing that somebody else is doing it, and that it's valuable, kind of ... You know, the reason why I started doing this is because I talked to some many people at the AAPT conference that I felt like, yes, there's value to doing it.

Participant-F I think trained staff would be my number one answer to that is that we need to have trained, qualified, dedicated staff doing these jobs.

Participant-R If somebody can look through what I have developed, and kind of help me bolster it, add content to it, in whatever format it may be.

Participant-Q So, I think, if those things were put in front of me in sort of like a quick and easy way, I would probably interact with them.

Participant-C I often also go to other forums. So, I've been using Mathematica for a long time, and Wolfram has some sites. And then, Wolfram has a forum which is dedicated to just discussion of different kind of physics problems, where people [Inaudible] systems and things like that, with equations [Inaudible].So, put it online. I'm just gonna go scour through those and try to figure out what would be a set of good questions to ask, [Inaudible].

Kinesthetic activities

Participant-I If I get feedback that it's definitely not working do I have backup plans, and other things like this.

Participant-I As I can find it right now I haven't found any resources for that type of activity of a physical body activity that helps with ideas in physics. Because there's lots of resources out there that I have found that are wonderful, like I said, I'm using other resources to help me aid in this construction of the class as I'm doing it now. But that's one thing that I would love to implement that seemed wonderful but seemed to require a lot of activity. And on my end that means it requires a lot of time that at the moment I don't feel I have.

C.3.6 Types of new things that instructors are trying

Instructional strategies

Participant-H Now that I'm using those ranking tasks, even though I'm using a small subset of what's in that book, they're doing one or two a week.

Participant-P So it was kind of a, let's get them to write, you know? I can read 25 papers.

Participant-U Then try to push them to do some pre-activities before class and then do some other activities in class.

Participant-P I try to have them doing things actually. So one of the things I've tried to do with varied success is sort of a pre-lecture question style thing, where I'll try to post a few questions kind of building off the reading and then when we get to that topic in class, have students present whatever their answer is and try to spark discussion that way. Like I said, it's varied in success semester to semester.

Participant-R So I think that is what I'm trying to still develop, is, look how the pre-lab content are so well structured so that the students get better and better understanding of the experiments.

Participant-R Anyway, the fact, where I tried to separate the theoretical background part from the detailed lab-specific aspect, I think that is the new thing.

Participant-N And did group exams. It worked really well in my class. I'm trying to see this semester if it can scale into the larger class. She's doing group exams in her class, and she's got group exams this week, so I'll be able to sit-in and kind of see how that goes.

Participant-I So, I implement it pretty much like they recommend. And if I don't get, if I have that less than 80 % one way or the other, I ask for them to talk to each other and then vote again. The one thing that I changed in the last year was enforcing that I want when you're talking to each other I want you to try and convince each other. And I want the groups that you're talking to to vote together. And that I've found to be a lot more effective and that it's leading to better discussions and it's leading to more changes in the votes. Because, before what would happen is they'd talk to each other and they'd vote and they'd vote the same way. Even if they disagreed they'd each vote their own. So the second condition I've found to be more effective. I've enjoyed it. So that was something new.

Participant-U I'm trying to avoid a little bit the big lecture where I'm always speaking in the classroom.

Participant-I I didn't like examples because I am not getting any feedback from them, if that makes sense. So what I've switched to doing, and this takes up the majority of the time I am not lecturing now, is I will post a problem and I'll have them work in small groups and I'll go around.

Participant-P At least some part in the lecture, have them do something. Like try to get them to lead a discussion or something in a group at their table.

Participant-M Because, sometimes if they feel like they are stuck; then they just kind of give up. But, if they have help from their peers; and their peers explain it to them, they don't, at least they can move on.

Participant-J so the in-class activities, the sort of weekly activity that they do where we'll spend 10 minutes with them doing some math calculation, or drawing distances to planets, that sort of stuff, that's pretty new. In the sense that ... having them take a photograph and send it to me, that's entirely new.

Participant-V I do like to lecture a little bit although lecturing sometimes seems like a bad word.

Participant-M I actually trying something new. Which, I have been applying from the inquiry a training diary cephum you see some influence.

Participant-M Then, I talk about different Hubblton part diagram. That was one of the major changes in the lab, which I really like.

Participant-Q One other thing that I try to do every now and then, I don't do this as often, but, I probably should more, is get them either graphing or drawing out figures that correspond to physically what we're talking about. I think that's a big skill that students have the opportunity to gain throughout physics is graphically representing the physical situations they're dealing with.

Participant-T And then on the very first day, I roll out like basically a rubric for participation grade. So, if they don't show up, there's a zero. If they show up and don't say anything, there's a one. If they show up and talk to someone about something about physics within their group or with the whole class, there's two. If they talk twice or more, that's three points. And three is the maximum they could get.

Participant-L I'm hoping that by moving to 10 points, maybe this is helping me. I have less dynamic range.

Participant-J I made a bunch of different tweaks. I did this goofy thing, which I think has been really fun, where they all sit in rows, and I named all the different rows after the different planets.

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Content related

Participant-S So, when I took over Quantum, the first thing I did was look for a book and there was a faculty member at our department who was from other university and suggested a newer book by another professor at other department that ... When I was a graduate student, the Griffiths Quantum Mechanics, that's the standard, didn't exist and so, I didn't use that book. I used it as a graduate student, but I didn't use it as an undergraduate. So then I was looking for a book and he suggested this new book by M. and I took a look at it and really liked it.

Participant-B We created our own textbook.

Participant-D But, the course content has actually changed. Last year we taught from a different book, and this year we are teaching from a different book. So, it's the same course but different material actually.

Participant-U Here it's very guided, it's like cooking book. That's something I don't like, I know it's very practical and convenient when you have 24 students in the lab, that well we go step by step and to get the result and everything's fine. But, I don't think, it is hard to know what they're learning by doing that.

Participant-G And so I guess that' the biggest difference is that in the way the labs were before, it was pretty formulaic and they pretty much were doing a worksheet and they were answering very clear questions and like they got a certain number of points for this and hat, and they knew all that. And now, there's much less specific guidance, either in the materials that we give them and also in the way that we facilitate their work.

Participant-M I've made the galaxy classification more inquiry, but not others. Its just hard.

Participant-W in course content, I added my PowerPoint all the time. I update it, I change examples, I change the homework that I assign.

Participant-R So I think that is what I'm trying to still develop, is, look how the pre-lab content are so well structured so that the students get better and better understanding of the experiments.

Participant-A A lot of the tutorials tend to be interactive either read and answer questions or conceptual or they have some where you have to match this concept to this definition or something like that. So anything that was more conceptual, interactive, anything that I thought was gonna be a little bit more engaging, I've left that for the pre-lecture stuff.

Participant-T But after the meeting I go back to my office and then I break the problem up into smaller pieces, or just add little comments.

Participant-P I'll try to have ... do the odd activity or worksheet that I've tried to make. I refuse to comment on the quality or lack thereof of some of my worksheets because they're pretty much all in-house made.

Participant-V The other thing was, I already have the PowerPoint there, I can show visuals that are kind of supplementing what it is I'm teaching.

Participant-Q That's a one sheet of paper. In the beginning, I had multiple sheets of paper and apparently, they're all environmentally conscious, because all of the sort of feedback that I got regarding the handouts was like, Yeah, let's cut down on the number of paper that we're printing. But, they all really like at least on sheet of paper for their handouts.

Participant-Q And the way I run class is I have handouts that sort of frame the lecture and frame the classroom experience. And that helps guide the students along. And so, that's a combination of some sort of inquiry based exploration that they do to tackle with some of the concepts that they're dealing with and then, also, just kind of like active examples for them to work on, that they then revisit as homework. So, yeah, there's a whole combination of active learning techniques that I try to employ throughout that time. Having the handouts really helps me with all the scheduling, so, keeping us on track time wise. And then, it sort of helps them see their progress bar as they go through that individual class period.

Participant-N And so, I thought,"Okay, well I can't just start from scratch. I don't have the time or energy." And so, I thought,"Well, the least I can do is modify my lecture slides so that students can work through the problem with me."

Participant-W So we developed a worksheet for it that's students had to work with.

Participant-W How much time I spend on what aspect of my theory, I'm trying to find a golden middle somehow. But also in course content, I added my PowerPoint all the time. I update it, I change examples, I change the homework that I assign, so right now, I have homework which I originally programmed on Blackboard for my other class and I'm using it also in Physics 243, the college physics, because it helps students to understand concepts better.

Participant-O We're gonna do a harder problem. I just made one up. They did it at the boards and it was actually pretty cool. They really get into it. It definitely was a little more challenging than Clicker questions on work and energy that I was planning on. I'm gonna try and do a little bit more of that. Just make class a little bit more challenging. And trying to respond to the concerns that the students brought up.

Participant-G We definitely based our first iteration on the Nexus curriculum out of Maryland, J. R.'s group.

Participant-F They've got this platform that we bought from Pasco, and it's basically a horizontal bar that spins on a vertical shaft that sits on the table. It's a neat little thing that we implemented, and it's neat. It works really, really well. I love it.

Participant-S The one that I talked to S. P. about was Quantum Mechanics, upper-level Quantum. I've made some changes there.

Tools

Participant-I I have displayed- so, the classroom is nice in that it's got a projector display that's off to the side so it doesn't block the chalkboard at all. So I've got displayed on the projector an outline of what we're gonna cover that day and then I also use the projector to do Clicker questions, Think-Pair-Share style questions.

Participant-C One of the [Inaudible] things that I learned at the [Inaudible] conference is using the ABCD card. So, I had some problems that I wanted to have ... which I thought that were conceptual issues that students often tend to get stuck on, and I wanted to see if pure instruction could help solve some of the issues. And I thought there was some remarkable progress that I saw in my own students, where I post some questions, they interacted with me, and then I let them interact with each other.

Participant-I The ABC specific is new.

Participant-U I've been using some of the movie clips just in classroom too. Watch the movie, well watch the clip, and then ask them questions about that.

Participant-D So, this pre lecture video, that's something new that we've introduced this year. That's not before.

Participant-B We have a lot of visualizations in the course because I'm interested in visualizations, and that was one of the reasons I got involved in it.

Participant-U Well if there are lots of YouTube videos there. I can have my own ones which are taken from my classroom. And put them on learning management system.

Participant-Q I put together just kind of like a 10 minute wrap up video. So, I have a Microsoft Surface, so, it's a touch screen that I can record. And basically, it's like a Khan Academy style video. I just put together whatever we went through that week. They have an equation sheet that sort of tracks all the things that they're going through, so, I just pick out that part of the equation sheet and run through like a quick "these are the concepts that we learned".

Participant-A But I think the biggest thing I've done differently is I've been trying to use a lot more of the mastering physics, the online components.

Participant-C I also tried one more method, and I wasn't very successful at it. And the other one that I had learned about at the new faculty workshop was using student groups and giving them boards and having them write on the boards.

Participant-C I wasn't able to implement it right.

Participant-B We would have group work at whiteboards. When we were first doing it, we would put the entire table of nine people up in one group. We realized we had enough whiteboard space to put everybody up in groups of three, which is of course much better, and so we switched over to that. But that was just suggested by one of the instructors in the course.

Participant-P They're at tables right, so give them a bigger whiteboard. And kind of say, alright as a group work these out.

Participant-P I'd use the very inadequately sized whiteboard.

Participant-A If it's something where I have them working on the white boards on the walls, I'll split them into groups just kind of counting off randomly and have them answer the questions in groups, typically three students I guess per group.

Participant-J Every other class they do some small group activity, and then I have them take a photograph of them on their phone, and then upload it to Moodle to show that they did something.

Assessment-evaluation resources

Participant-O That's one thing we do, too. With the pre-session, the pre-class quizzes, the students have a chance to send us feedback every class. Before every class, and we look at that before we go into class. I usually pick some student's comments to respond to. It gets that dialogue going, which is nice.

Participant-S I assign a reading quiz before every class. So, I sign each section and I asked the students to summarize the reading or ask me something that they don't understand about the reading.

Participant-Q That's a huge part of the FACT systems, it happens during the semester.

Participant-P I tried peer review too. So I'm making them submit versions of their, that was the last class, submit versions of their paper to classmates. And then have like 2 weeks for them to peer review comments and get it back. And hopefully that means, at the end of the semester, what I read is better.

Participant-I I guess Minute Papers is the buzzword, where I have daily feedback where I ask them to turn that in.

Teaching strategies

Participant-H I'm using those ranking tasks, even though I'm using a small subset of what's in that book, they're doing one or two a week.

Participant-U Then, try to push them to do some pre-activities before class and then do some other activities in class.

Participant-P So it was kind of a, let's get them to write, you know? I can read 25 papers,

Participant-P I try to have them doing things actually. So one of the things I've tried to do with varied success is sort of a pre-lecture question style thing, where I'll try to post a few questions kind of building off the reading And then when we get to that topic in class, have students present whatever their answer is and try to spark discussion that way. Like I said, it's varied in success semester to semester.

Participant-R So I think that is what I'm trying to still develop, is, look how the pre-lab content are so well structured so that the students get better and better understanding of the experiments.

Participant-R I tried to separate the theoretical background part from the detailed lab-specific aspect, I think that is the new thing.

Participant-N And did group exams. It worked really well in my class. I'm trying to see this semester if it can scale into the larger class. She's doing group exams in her class, and she's got group exams this week, so I'll be able to sit-in and kind of see how that goes.

Participant-I So, I implement it pretty much like they recommend. And if I don't get, if I have that less than 80 % one way or the other, I ask for them to talk to each other and then vote again. The one thing that I changed in the last year was enforcing that

I want when you're talking to each other I want you to try and convince each other. And I want the groups that you're talking to to vote together. That I've found to be a lot more effective and that it's leading to better discussions and it's leading to more changes in the votes. Because before what would happen is they'd talk to each other and they'd vote and they'd vote the same way. Even if they disagreed they'd each vote their own. So the second condition I've found to be more effective. I've enjoyed it. So that was something new.

Participant-U I'm trying to avoid a little bit the big lecture where I'm always speaking in the classroom.

Participant-I I didn't like examples because I am not getting any feedback from them, if that makes sense. So, what I've switched to doing, and this takes up the majority of the time I am not lecturing now, is I will post a problem and I'll have them work in small groups and I'll go around.

Participant-P At least some part in the lecture, have them do something. Like try to get them to lead a discussion or something in a group at their table.

Participant-M Yeah because sometimes if they feel like they are stuck; then they just kind of give up. But if they have help from their peers; and their peers explain it to them, they don't - at least they can move on.

Participant-J So, the in-class activities, the sort of weekly activity that they do where we'll spend 10 minutes with them doing some math calculation, or drawing distances to planets, that sort of stuff, that's pretty new. In the sense that ... having them take a photograph and send it to me, that's entirely new.

Participant-V I do like to lecture a little bit although lecturing sometimes seems like a bad word.

Participant-M I actually trying something new. Which I have been applying from the inquiry a training diary cephum you see some influence.

Participant-M Then I talk about different Hubblton part diagram and yeah.. That was one of the major changes in the lab, which I really like.

Participant-Q One other thing that I try to do every now and then, I don't do this as often, but, I probably should more, is get them either graphing or drawing out figures that correspond to physically what we're talking about. I think that's a big skill that students have the opportunity to gain throughout physics is graphically representing the physical situations they're dealing with.

Participant-T And then on the very first day, I roll out like basically a rubric for participation grade. So, if they don't show up, there's a zero. If they show up and don't say anything, there's a one. If they show up and talk to someone about something about physics within their group or with the whole class, there's two. If they talk twice or more, that's three points. And three is the maximum they could get.

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C.3.7 Types of ways that instructors decide a new instructional practice is working

Benefit Students-based on a written evidence

Participant-U I'm having an exam this week so I get a little bit more feedback then from what I'm being having with homework and back in class.

Participant-U From the survey and the grades, how well they learn, how well they think they're learning, I will try to compare with results from previous courses just to see where I'm standing in the overall.

Participant-W Then I actually put a similar set of questions on the test, and students did pretty well on those, so they learned quite a bit.

Participant-Q Part of it is assessment based, how well they're doing on like quizzes and exams.

Participant-Q We actually have an interesting set of metrics that we can compare to here at the my institution. They all have an academic order of merit. It's essentially like a grade point average. But, we have access to all of that information. Like, there's a system that has all of their metrics in there. So, I can plot out how my students are doing normalized to how they do in all of their other courses. And that is a way in which I think I can do a good job of kind of like checking how effective I'm being at teaching them.

Participant-E The objective measures of the student learning continued to be high. The faculty who have gone through this say that, "Yes, this works for me. I can now do this myself after having being into practice." They continue to do it effectively, and they're willing to come back and teach the class again.

Participant-B It was a robust assessment but in particular what we always show is before and after with 25 multiple-choice tests that was validated. We compared that to other courses at my institution with the same demographics and showed a big difference in the outcome. The reason it's important to do it with the same demographics is people will tell you that our students are totally different from any other students in the entire world.

Participant-L But I certainly don't feel like if I look back at a problem that I had asked students to do, or a test I'd ask students to do five or six years ago that my students now would struggle with that material. So, I think it's still a good thing and it's responsive to what my students are hoping for.

Participant-K We don't know if it's going to end up being more learning, better scores, just happiness factor, we don't know. It's all just a crap shoot right now.

Participant-A I've been teaching long enough that my first exam, the average is almost always a 64. Yeah, and you try and ... I work to try and bring that up. I want some kind of a spread because not everybody is at the same level, but this exam I think the average was a 75 to begin with and this was four weeks into the term.

Participant-K On the common tests. So, because I was doing the candy questions and the other sections were not, let's say the average was 40 out of 60 with a standard dev of six, and my class would be a 46. I would be like, "Well, the only thing I can think of, other than me being this fabulous teacher, which we know I'm not, I'm just a regular ordinary Joe, is these candy questions, because it's multiple choice oriented, it's making them think about it, and it's peer learning." So yeah, don't know.

Participant-F One of the ways I test understanding is at the end of the class each student actually has to do an exit quiz.

Participant-U Well so far by feedback in classroom, and I think that some of them are really responding well.

Participant-U Well I'm giving a survey on Wednesday to get feedback on how well I'm doing, how well the class is doing, and how well they think they are doing. Just to see if that works for them or if it doesn't work for them.

Participant-U I mean it's going to be a blind survey, so I expect that they sincerely tell me how- what are the problems that- the aspects that concern them. And what would they want to keep- what works.

Participant-U Just by talking or in any classroom just by seeing how they are doing. But the feedback that I'd get is how well they're doing, not how they feel they're doing, so that's why I want the survey.

Participant-U From the survey and the grades, how well they learn, how well they think they're learning, I will try to compare with results from previous courses just to see where I'm standing in the overall.

Participant-O Just because of what they say. I see them in office hours and they'll just start talking about it. For the most part they've given us pretty good feedback. We're really pushing them hard and I think they realize that they need that. Even though it's extra work they are appreciating the fact that they're getting something out of it. That's what they think. That's what I'm hearing from them.

Participant-C I've just done a mid semester survey, so we'll see if somebody points out that it was good or bad. Maybe I'll go back to it and do it in a different way.

Participant-D But, we got from the feedback, it seemed like the students didn't like that because some sections cover some material which was not covered in other sections.

Participant-D Most of the students complained in the feedback that they don't have time to read. Or they don't like to read. Put it that way. So we thought maybe it's better to have a video because they like to watch videos.

Participant-D From the feedback that we have got so far from the students they are actually liking it. And they find it much more instructive than reading themselves.

Participant-Q I've gotten some relatively positive feedback in general.

Participant-Q I have a couple of options as far as feedback from my students goes. They're all required to fill out student opinion forms at the end of the semester and so, that's sort of one soft feedback mechanism that I have. Which, again, is coupled with all sorts of controversy as to how effective that actually is or what those student opinion forms actually mean. I take specifically those student opinion forms to give me an idea of the tone of my classroom. And that sort of verifies that my students are, at very least, kind of like feeling good about what they did. Whether they actually learned anything or not, I don't think that comes across in the student opinion forms at all. But, how they feel about what they did.

Participant-N But the feedback that I had gotten from the students is that they like it quite a bit.

Participant-W We're gonna look through the test results, and we're gonna try and see how students did, what did they learn, how was it beneficial, and present it at the meeting.

Participant-N I've heard feedback from students because I ask them on the student evals at the end. I'm like, Please give me feedback on this particular activity. What worked? What didn't? What could make it better? Was it value for you? So, I'd gotten good feedback about that.

Participant-F It seems to be quite effective. I've gotten a lot of good positive feedback from students that go through the program and also come back later on after completing or matriculating to other universities, and they tell me that it was an effective and worthwhile approach to physics.

Participant-F Very often I'll have the students write a paragraph about what was the most meaningful aspect of the lab that they just took.

Participant-F How do I know that it's the labs that are doing it other than the students telling me.

Participant-B It works pretty well. Our student evaluations now are about the same as before we started this, so it worked pretty well means the students like it well enough.

Participant-I I do, I guess Minute Papers is the buzzword, where I have daily feedback where I ask them to turn that in. I do it absolutely daily at the beginning of the term.

Participant-I I get direct feedback because my minute papers.

Participant-I For example, I had feedback on my- this wasn't a feedback on a feedback sheet, this was from my end of the year review, that was very harsh saying that I didn't listen or ... not didn't listen, that I didn't like and I played favorites against foreign students.

Participant-V I wanna respond to them. I'll even ask them for feedback at certain points, after exams and whatnot. I've looked at their surveys and what it is they want; make small changes.

Participant-V I'll have them fill out these sheets, like muddy cards basically. I say, what did we learn this week that you think you have a solid grasp of? What did you struggle with, not even just content based. What are you struggling with or what's an issue?

Participant-V He had a student come to him after the first quiz and say, You're doing these things bad.

Participant-E This really does work better. Yeah, you start to get the feedback. The things that you thought the students were struggling with that's not what they struggle with. When you're in studio, you really start to understand how the students think because you're talking to them in a way that you're not in the lecture.

Participant-E I was reading her student evaluations to the class. The students were all complaining that, Why can't we have what we had in the first semester? How come in the second semester we don't have all the stuff which we know really help their learning and which we really like? The students are part of the rally as well.

Participant-L So, every year I get feedback that the problem solving sessions that I do where we might spend an entire day or half a day working problems, are very beneficial.

Participant-L That I get feedback that the students appreciate that, and so that's not exactly data that's like, "Yeah, they're learning more," but they feel better about the process when they have more time doing that. And that in and of itself, I'm okay with. I think that's kind of a win, that students feel like I hear them, I hear what their needs are, and I'm trying to meet those needs.

Participant-M I thought that was good feed back from their peers and from me too. I think it works that much better.

Participant-R But my immediate recourse is to just look for student feedback in class, or discuss with them, is it working or is it not working?

Participant-K I guess we're pretty much using the FCI. We do the Force Concept Inventory at the beginning and end of the semester. We've seen pretty strong scores at the end of the semester compared to the beginning.

Participant-L I think there's a couple of things that I look at, but I haven't been really consistent in my data collection. I think in general, my students are doing pretty well compared nationally. When I have made time to do the FCI pre and post, my hate gain is as good as or better than active learning across the country. I can't quite remember where my numbers are at, but I want to say we're up around 50 %, 60%, something like that. I don't always, though, make time. So, I didn't actually do a pretest this year because we ran short on tome, and my research comes second to my students' needs, and my students needed more time working.

Participant-G It was really sort of about modeling. So it was sort of like we were trying to look at how their discourse around when they were sort of looking at data, trying to make sense of it, compare it to a mathematical model, so things like fitting, which they don't understand is modeling. But we'd like to help them get there. And so that was an initial step. We're administering the E class.

Participant-K We do the Force Concept Inventory at the beginning and end of the semester. We've seen pretty strong scores at the end of the semester compared to the beginning, so I think the stuff we're doing is working.

Participant-T I have the student do the pre and post, and which actually, the results were consistent what I thought at the time would happen would be that after help taking the class, student felt like less like a scientist than they did before.

Participant-R My class's part is spreading in the E-Class software, which Colorado has put together. So this will be the fourth time I'm offering it. So that gives me some idea as to what has worked and what hasn't work.

Participant-E we had baseline data so we can show. Okay. This is what we looked like when we were teaching the traditional way, and this what we look like when we teach now. She thinks people found it compelling.

Participant-Q And that's a huge part of the FACT systems, it happens during the semester. And so, I almost always come up with at least one actionable response that I will change during the semester. And I discuss that with my students. So, I will take the result of that FACT and, actually, sometimes I'll put it up like on the projector and say, this thing totally makes sense. I understand why you guys are concerned with that.

Participant-D So far we have not heard any complaints. We'll see at the end of the semester. After the evaluations we will maybe learn how it went.

Participant-Q Somebody who, like either a fellow faculty member or somebody who's trained in probing the classroom, talks to my students for something like 20 minutes and has them put together lists of things that help them learn and they think hinder their learning or could be improved upon. And then, that person compiles all of those and has a conversation with me.

Participant-B I would say, "Gee, I'm really sorry that they don't like it, but they're learning twice as much." That's why it did not just disappear after that disastrous, because I could say that and I could point to evidence and journal publications that showed that.

Participant-G They did some audio/video filming. We did IRB, we did all that stuff. And he also did some interviews 'cause he was taking an interviewing class as a PER student. And so we have some qualitative data that we've been analyzing to really probe more attitudes.

Benefit students- students affect/learning-based on an instructor's intuition

Participant-C I actually asked students, just in passing, Do you guys like this? And the students were happy about it. Some of them were vocal about it, they were like, Yeah, we like this, we want to see more of this stuff. So that was, you know, I thought that was very bright and positive, for me.

Participant-M I think its working really well because, we are able to finish everything on time and it just didn't seem to be having a lot of fun. Especially, when they're making presentations they're really funny.

Participant-U If the students are enjoying that.

Participant-O We'll spend a few minutes on the Hopper Popper. Everyone will have a Hopper Popper to play with and they have to figure out how much potential energy is stored in it. That'll be fun, they always love that one. That'll be fun tomorrow.

Participant-Q I honerd in on how that works and that was mostly by reaction to my students over my first couple of semesters.

Participant-C I did and that my students, I think. Found exciting.

Participant-N Students liked it. I continued it last academic year and students like it. So, I'm just continuing to work and modify it.

Participant-G They did some audio/video filming. We did IRB, we did all that stuff. And he also did some interviews 'cause he was taking an interviewing class as a PER student. And so we have some qualitative data that we've been analyzing to really probe more attitudes.

Participant-G LAs as everybody knows, are lie these awesome spies. And so they provide us feedback, they really kind of give us a temperature of the students.

Participant-K They'll be sleepy, because they're always sleepy, and then I'll say, Okay, now a real life story. And then all the sudden they're awake, so I know it works.

Participant-K Then all the sudden they're awake, so I know it works.

Participant-Q Keeping them awake is one aspect of it.

Participant-U It seems they do but they are struggling a little bit more. I don't know if they're struggling because the physics, because the effort that they put in it, or because this method is new to them.

Participant-C But, at the end of the exercise, not many students got to the position where I wanted them to have gotten.

Participant-O The sense I got from the class itself was that it was working great. Everybody seemed to get into it on the boards and do a nice job with it in the end.

Participant-N That seems to be working pretty well.

Participant-I I have found, in my opinion, positive response from it in that I get more discussion in the Pair-Share part and I get more people changing answers.

Participant-K I walk around the room while they're doing this, and I can hear the misconceptions being reprogrammed by their peers. Oh, I get it now and then all of the sudden, you know, so, there's rules to it of course. Somebody can't just stand up and say. The answer's C, and they all click C. No, that doesn't work. There's no candy for that one, so they know not to cheat. I've been doing that now for a couple of semesters, and it's been very successful. I've been very surprised.

Participant-R I would have the essence of the frequently asked questions from the students. And then I go back and decide,"Okay, I may have ..." for example, the fix could be just spending a little more time introducing the content to them. Or it could be providing some additional reading material. Or if I can with reasonable effort show them some simulation which will give them more insight ... let me think of ... for example, the [Inaudible] experiment is one example where I had to provide them some articles to read, and then discuss the conclusion of that article in class.

Participant-T I have this idea and I want the student to think in this way, but I'm not gonna tell them how to think. But I want them to tell me how they're thinking it through, and if all the questions they ask are things that I have anticipated, then that means that we are of the same mind. If they sort of ask questions that leads down a completely different path from a path that might not be fruitful, then I say that maybe my approach didn't work as well.

Participant-C So, I repeated the same exercise of them coming back to me and telling me the answers. And there was a remarkable change in their answer after peer discussion. And students were much more confident after they were ... Before they got into groups and talked to each other, you know, some of them were like, Oh, I'm not really sure about this answer, but after, pretty much all 19 of them were like, Yeah, we're sure about the answer. And that was nice.

Participant-S I don't know how I knew that. I guess it was just sort of a feeling that I had at the end of the class that, at the end of that tutorial that the students weren't seeing what I wanted them to see, whereas like in the quantum mouse tutorial they were seeing like, Oh, I can see now how to use this matrix to ... I can use the Matrix in calculating the expectation value or I can use Dirac notation and the probabilities in calculating the expectation value.

Participant-I So, I just kind of wander around and see how they're doing and I'll pull them together because I teach kind of like a problem solving rubric of draw a picture then state the ideas, that type of thing, and I'll pull them together after the first two minutes.

Participant-C Then, I felt like it didn't work very well, so I got scared and I didn't do it.

Participant-L I just float around. I facilitate, I see where groups are at, I get a sense for who's struggling, who's not.

Participant-I I'm not sure I have something that works best or worst, I just decided to try all of them out to see what was working. But I do at least three of those questions, I'd say at three, at least two. I strive for three every time. And then the other thing I have found, the students really liked examples.

Participant-T I feel like I'm doing it pretty well.

Participant-S I don't know. That feels very touchy-feely. I mean, I didn't do any sort of assessment. But when I did like the quantum mouse tutorial, I could see the students understanding of like a two-stage system and how to visualize it in Dirac notation and then how to visualize it using a matrix notation.

Participant-Q I pride myself on my ability to read my students. So, that's sort of my first line of defense is how interested my students seem.

Participant-U I mean usually try to spend like 15 minutes at the end of the class and then give them a problem, and then make them work in pairs and then I just go around and see how they're doing and ask them questions. So with that I can see how well they are doing or where they're struggling.

Participant-L I feel sometimes like I do the same thing 10 times in a row as I'm doing these problem-solving sessions, but I think it's actually more effective because the students are getting it when they have that question. When they need that intervention.

Participant-V Where they're not looking at their phone or when you ask them questions about what it is that you're demonstrating, it's not like pulling teeth. They're just excited. You can kind of tell, it's an easy tell if somebody's interested in what you're talking about or if they're not...You can see it in their eyes or their body language. It's kind of like the body language, try to read the body language. You get people to talk more when you do demos.

Participant-U It worked pretty well. I was very happy how it worked there. That- well was different groups, so it was like between 15 and 35 students, and well they really were very engaged in doing the pre-class activities.

Participant-U Walking around the students in a classroom, while they are solving a problem. So, with that I can see how well they are doing or where they're struggling.

Participant-C The ideas came well, so they worked, but I'm not sure every time it's gonna work.

Participant-U And they seem very engaged.

Participant-C With the ABCD cards, even those people (low functioning groups) had to respond, because it was peer pressure, right? Everybody else was responding. So, even if you were confused, you had to do something. So, you had to break out of that cycle of using Facebook or Twitter, and come to the class. And I think that was what was missing in my group work, in the previous active learning activities that I was doing.

Participant-S I'm only going to address the things that they ask me questions about in class and on end-of-course statements, sometimes students complain about like that. They say like, "I don't know what I don't know." And I understand that comment. But on the other hand, I feel like if you're reading the book really carefully, in principle you're trying to go through like the examples and understand the examples and if you can't do it then that's something you can ask me about and I can address, but if you don't ask me a question in class I say like, I'm not going to talk about that, but there'll be a homework problem on it. Then you'll know that you don't know and you'll have to come and ask me questions at that time.

Participant-T They always ask question, but I guess it depends on whether the questions are in a away that I predict or if their question is in a way that I did not predict.

Participant-N Questions that the students ask.

Participant-Q Talks to my students for something like 20 minutes and has them put together lists of things that help them learn and they think hinder their learning or could be improved upon. And then, that person compiles all of those and has a conversation with me.

Participant-T I was actually really surprised how well that worked in the last several semesters. It's just they talk, and they don't stop talking. So, yeah. So that's the thing I'd done with the discussion group.

Participant-T So like sometimes, the problem is straightforward and I could hear like everyone's converging to the correct answer. Then I could just stop the discussion and say. Okay, you know, I hear everyone's converging to this, and it sounds like everyone's have the correct idea, then I could move on.

Participant-M If I can see students putting out that there are similarities between theirs and another group or where - Sometimes I see them they don't admit it by hear it, they don't admit it in their presentation but I hear it, that they disagree with each other[laughter] especially the angled ones. Then I hear afterwards, awe I knew it was an angle, but my group members decide to make it this, in this group, so we went with that. When I hear things like that I feel like its working, or when I see that they are enjoying it.

Participant-E You really start to understand how the students think because you're talking to them in a way that you're not in the lecture.

Participant-C They were getting up from their seats and going to the board and presenting. And that already sort of gave me a feeling that they were learning more that they were in the other classes.

Participant-R And then I also get some insight when I read through the lab reports, which they will turn in.

Benefit instructors

Participant-C It did work. I thought it worked.

Participant-D So, I found it quite useful actually.

Participant-F It's a neat little thing that we implemented, and it's neat. It works really, really well. I love it.

Participant-H Yeah. So, I'm working on figuring out how well it's working.

Participant-M I think its working really well because we are able to finish everything on time and it just didn't seem to be having a lot of fun. Especially, when they're making presentations they're really funny. [laughter] in the names. When they say the names, it is really funny. They get to share that with other people. I think they have a lot more fun with it now.

Benefit department and institution

Participant-L We have done a lot of data analysis on success rates in our physics class. We feel like we're kind of stuck at about an 80 % success rate, or a 20 % DFW rate.

Participant-B It worked. Although, I really don't like to couch it terms of failure rate, I think this has improved everybody's educational experience.

Participant-B I did a lot of testing over the course of this. If you look in the low, medium, high compared, if you somehow lumped the students into low, medium, high, the percentage gain is the same across those, the low, medium high, so everybody benefits from this. But, the ancillary phenomena is the failure rate goes down, but you're talking 5 %of the students. I think it's improved the educational experience for 100 % of the students, so that's why I don't emphasize failure rate.

C.3.8 Challenges physics instructors experience related to applying new instructional practices

Classroom practical consideration

Participant-K So the changes, adapting to that. Because they're putting this new content in, it's shortening the amount of time that we spend on certain subjects.

Participant-I The class, probably the biggest thing I struggle with is the actual room.

Participant-J But, in a class where there were like 35 students in there, and I'm trying to grade 10 posters and 10 PowerPoint presentations, and give 40 pieces of feedback, and it just wound up being too much. And I don't think it was ... the products weren't great, and they didn't get good feedback, and I was exhausted.

Participant-T The limitation is like the room that get assigned in, because there's so many sections, you can't all get like a scale-up classroom. But, I'd done it in both kind of classroom, but it's best when you can move the tables and the chair around.

Participant-D Inspired by past experience in a reformed space.

Participant-N I just am still working on getting a feel for managing the lecture time.

Participant-H I'm using the ranking tasks, and because I'm doing more small group work ... And, I knew this was gonna happen. I've had to slow down. And, I'm gonna be cutting out a lot of topics at the end of the semester that I would otherwise get to .

Participant-M I'm thinking to do something a little bit about the phases of the moon too. I was going to do it this year, but I didn't. I didn't have time. It's always easier just to go with what you've previously done when you're busy.

Participant-E You have to be there. You have to be in the classroom for more hours. You have these set meetings where if you're just teaching Quantum Mechanics by yourself you don't have to meet with anybody.

Participant-B But, lecturing is the easy way out. I don't think it's particularly effective, but I've got a lot of other things going on, and I've done by duty as far as mu institution education goes.

Participant-B I tell the students that this a terrible way to teach, but it takes too much work for me to be interactive.

Participant-O It takes more time for me to do the studio course. I'm in there more time than I was in the old days. That's challenging as well, but it's also fun. I get to know them a lot better.

Participant-Q All of that constrained within time.

Participant-A There's a lot to cover. I'm used to teaching on terms, and most of my teaching, just about all my teaching was in the other state and between the community colleges or the universities there, and they all had the same schedule. You covered the same material every term. So, I'm adjusting to covering to semester schedule now I guess. We'll be doing thermo in November whereas I wouldn't have done that until January or February. The time is the same I think, but it doesn't feel like it. I definitely feel like I've got my schedule laid out, these are the days we're gonna do these things, and I feel like I have to stick to that, because if I get too far off track, then not only are we not gonna finish the material this term, but then next term is gonna be off.

Participant-M The major struggle with that, is not enough time to teach the content that I want to because, I tend to have to cut up stuff, in order to make time for the activities.

Participant-U So, I don't know if it would be doable to have some groups to one thing and other groups to other thing. I don't know if that would work here or not. That's not going to happen.

Participant-R I mean, this is what I'm personally fighting. Because every course has a certain level of rigor.

Participant-H Definitely challenging is students having a misconception as to what the class is for.

Participant-P It's hard for me to keep track of who actually engages in the discussion.

Participant-D And only at the same set of few students in the front rows, they always raise their hands. And other students they just sit there. They don't do anything.

Participant-J So, the challenge of providing feedback on this project, which was just too much.

Participant-L Grading. I'm a particularly slower grader. I think I am worse at it than most of my colleagues and peers. You can ask S. and he is frustrated with the pace at which I grade as well. It kind of dominates my life when I have something out, so I have a test sitting here. I gave it yesterday and my goal is to get it back in week, I often can't. It takes me forever to slog through, really trying to understand where my students understand things versus where they don't, and when they don't understand things, what is the value of their misconception?

Participant-D When they start discussing and then, so if I'm running out of time, then I just tell that we should stop discussing and then maybe go to the next part, and sometimes they still keep talking. Some of them. And it's hard to keep them quiet. But I have to be a bit more stronger I guess.

Participant-R Students haven't done Modern Physics yet, but some of the experiments are from Modern Physics, they might have seen it in their introductory physics course, usually they don't remember it.

Participant-O You get to know the students, and where they're coming from, and what explanation worked for them. That's a challenge.

Participant-S The student population is a lot more mixed, when I taught Mechanics versus when I talk Quantum.

Participant-S I think if you asked a similar question about Classical Mechanics, which I've also taught, that course was very challenging because there's a wide variety of skill levels in that course and when I taught it, and commitment.

Participant-P I think my biggest issue is them not all, like I can't, it's hard to expect them to be all at the same place with the varied backgrounds.

Participant-P You have diverse course backgrounds. Some of the students haven't taken Thermal Stat Mech. yet. Some have. Some haven't taken Quantum, some have. So there's a lot of variation in that, and it's hard.

Department cultural consideration

Participant-Q The big thing with that is we have a large constraint in that we all need to finish at the same time. There's a lot of professors that are all working on their own schedules to get there.

Participant-E There are always some people who are simply not convincible by data or experience.

Participant-B He also subsequently did not get tenure. We do not tenure on the basis of teaching. We tenure on the basis of research accomplishments, which means your recognition outside of my department by the research community that you are in. If you don't rank there, you don't get tenure.

Participant-I I think mostly what I'm struggling with is there is an expectation of teaching excellence and enough support around that that I'm finding myself dedicating 90% or more of my time towards the teaching and I'm worried about my scholarship. So that's, I think my biggest concern is not on the teaching side. I've got lots of support here. I'm more worried to make sure that I can still publish and that I can make tenure because that's more on my worry. I'm less concerned about the teaching.

Participant-B The first term that we did this on term with 800 students was pretty disastrous because the people hadn't been trained.

Participant-B I think when we began the faculty had no idea what they were supposed to do, and that was my fault. I didn't train them well, and what they did was lecture. That was deadly.

Participant-U Because there's much newer faculty that really want to change this a little bit because there are some things that are not optimized, and they should be optimized.

Participant-E There are some people who we put into the course and it just really doesn't work.

Participant-Q There are plenty of sort of old fogie kind of professors that teach it the same all the way. But, we do actually have the, I would call it, bandwidth to think critically about how we teach our courses.

Participant-B Well, there are faculty who still think this is a terrible way to teach, but those tend to be older faculty.

Participant-B That's when we started breaking up what the material, they had to force them to do interaction. There's still not enough interaction. We still get people who go in and lecture. If it's a tenured faculty member, it's very hard to change that.

Participant-E The more senior people are more dubious about it, because they figure I already know how to teach.

Participant-W Because of the size of the class, I am restricted to what I can do.

Participant-W But, unfortunately my classes are all the wrong size. Too big for the classroom, or much too small. The small ones I don't have a problem because I can work around it since they also involve laboratories, but the big ones are the challenge.

Participant-I I've found that that is inhibiting things that I'm able to implement. Like, I also don't have a computer in the classroom. Like, I also don't have a computer in the classroom. I have to bring in a laptop which means for like demo setups and other things where you have to hook things in it's a crap shoot whether it'll work. It's enough that now I have stopped doing it this term.

Participant-A I'm getting familiar with the stock room or the lab prep room, so that's always a bit of a challenge using what I have used in the past or know, then seeing the materials they have and how I can either write a new lab or use what I've done before. It's always an investment.

Engaging students

Participant-U People working outside, and yeah trying to focus into some courses and not the others. I mean there could be lots of things going on that are out of, things that are hard to control.

Participant-U The fact that, so if they don't have time to study then it makes sense to me that their grades, it's reflected in their grades.

Participant-M I think one of the challenges is that when they work together in groups, its hard to tell whether some people are just passive observers.

Participant-V I had a much easier time building a rapport last year with my students in my introductory class as compared to this year. They're a little more shy. I don't know if it's something I'm doing differently. I don't know if I can structure the class differently.

Participant-P I think the class is at critical mass where 3 people talking doesn't seem like everyone's talking

Participant-P I think with the upper division, this is, I've only taught this and Classical Advanced Mechanics, at it's upper division. Classical, I always found for most students, because it's every day experiences and that. They're a little more willing to talk and engage in it. But, with this one. Because, everything's so abstract. Like out of the realm of every day experience. Students are really hesitant to engage.

Participant-P And one or two students will answer, and then everyone will sit there and just kind of stare, like, tell us if they're right or not, rather than thinking about it.

Participant-R So I think, if I'm not able to provide a structured way for them to learn some software skill, then either I have to put some effort to fix that problem, or come up with an easier way to analyze.

Participant-Q So, keeping them awake is actually a pretty significant challenge. Even with only like 15 minutes out of 45 minute or 50 minute slot, some of them are still falling asleep during that like interspersed 15 minutes.

Participant-B I knew how to handle the faculty, although some of them you can't handle. The major surprise to me was that the students disliked it so much. In retrospect, I can see why they disliked it, but that was totally out of the blue to me. I just didn't expect that. I think part of that was we didn't tell them really why we thought this would be better for them. We didn't do a good job of justifying what we were doing. But in subsequent years we did.

Participant-I I think the biggest that I'm finding right now with my current class is I get very little response out of them.

Participant-I I like to ask questions and so there's a lot of silence here when I say, okay, let's think about this, and I get up on the board and okay, in this situation what happens? And I just stare at them and I get nothing from this class. So this class is awkward, but most of the time you'll get a few responses and you can hammer it out.

Participant-I But this class is a struggle to get anyone to talk. I'm not getting responses now. So, you'd probably see a lot of silence as I ask a question and wait. So, if you did that tool of ticking of what's going on at this minute, you'd probably have a lot of me starting at the class and the class staring back at me in silence.

Participant-I And being able to focus in and get them to help drive the discussion, but they have to respond in order to do that. So, this term I'm finding that most challenging.

Participant-O Just trying to put yourself in their brains. That's challenging. Each class I've got 81 kids and they're all different. Anytime anybody asks you a question, you sort of go, "What really is this person getting at and how should I explain it to that individual as opposed to this other person?" If this other person asks I might have to explain it a different way.

Participant-F Certainly the students and the diverse population we get of students at a community college has been very formative for me and the regular interaction and push back I get from students who come in and need things to be explained to them in very, very different ways in order for them to appreciate it. The need to try to find different ways of explaining a familiar concept is very challenging, and it leads to a lot of growth as an instructor. I'd say more than anything else, it's working with students is what has been my responsible for my growth as a physics educator.

Content materials

Participant-P I should say, I found of bunch of textbooks I like. But, I haven't found one that I think is suitable for the course with half the students having never taken quantum, ya know? And have the students have. And half the students haven't taken thermo, and half have. It's really hard to have students equally prepared I guess.

Participant-U I don't really like the book.

Participant-U It doesn't spend too much time describing the concepts, and it's- I mean I find it a little bit mathematical and not that physical. So, it focuses into well these are the question and we solve this is and this. But it doesn't spend time talking about what physics is behind all those things. I mean yeah the math is important and you need the math to do solve the question and to solve problems, and you need to know what equations you need to use. But it skips some points that I think it deserves- some of the points that the book skips, I think they deserve a longer explanation or at least just an idea of why that happens, just he starts- at some point just present some equations and say, "Okay that's a question that we need to solve" But it doesn't really explain why and how to get to that equation. That's why I don't really like- and the problems looked more like just training how to use one tool but not actually go into problems that really give you move more information about the nature."

Participant-S Let's say in my circuits course, which is this outline of a theory manual written by a faculty member in 1986. For me personally I find it hard to teach a class without a book for students to go to.

Participant-U What I'm finding also hard is to find problems that are exciting, that are different.

Participant-S I find ComPADRE hard to navigate and maybe that's just because I'm an old curmudgeon now, but I don't go to ComPADRE to look for things.

Participant-P They're pretty much all in-house made, because there's not much for Solid State undergrad physics out there.

C.3.9 Attitudes toward the implementation of new instructional practices

Enthusiastic-positive

Participant-G So, I guess it was just like it felt better, it just felt better. It was very selfish in some ways. I felt like I was wasting my time less.

Participant-J And I think it's gonna be really good. They're gonna think it's really goofy and stupid, but as all the students acting like particles bumping off each other, I think that'll be really fun.

Participant-O I have fun doing that. The studio environment is great because you get to know the students so well. In the lecture class it was like I saw them for three hours a week and they're 20 rows back. I probably know their name, but I don't know them very well.

Participant-Q I've always tried to add something every semester to what I'm doing. I've gotten some relatively positive feedback in general. But, I try to stay on top of just like adding new components, trying new things out in my courses. And then, I also keep track of that for my tenure package of like things that I'm adding and how that's going and all of that.

Participant-E The whole faculty members who've gone through this apprenticeship they keep saying things like, I had no idea about this. Now I see this is much better for the students even though for the first time it's more work for me but it's clear that it works better. I'm going to use this same technique in my upper division class, and so forth. I think the value of it is clear.

Participant-B I was just so overwhelmed by making the changes that I made that it was just this brutal struggle to keep it going.

Participant-T There's changes that I made and plan on making on both sides.

Participant-T So, I think having multiple sections actually is good because even within one week, I could actually iterate new idea. So, actually I think it works pretty well.

Participant-T So, the thing is that I'm always trying to do things slightly different and approach thing differently.

Participant-B They continually introduced new things.

Participant-V I think maybe my philosophy on the teaching is like,I think lecturing is okay in small bits and you have to break it up. I think the problem solving was meant to break up that monotony but it serves a purpose more than just that.

Participant-I That's an excellent question. I don't know on this individual problem. If I knew I'd probably go after it. Because my support in the department here and in the school at large is huge. Like, I've got a lot of support. If I knew what resource to go after I would probably do so. So, I don't know on this individual struggle that I'm having. I think that's the biggest issue is I don't know.

Participant-L If we aren't going to do it well, why are we doing it at all.

Participant-J I would be open to more suggestions of good activities that people have, because I definitely recognize that my class is not as interactive as it could be.

Participant-P Sounds like a lot more, I feel like I don't have any excuse for not doing better. Bunch of books and help from people.

It's hard for them [at first but it gets better]

Participant-F It takes a lot of work though to set all that up and again, just much harder to do it this way than traditional physics instruction where the students follow a recipe and then write long reports about it afterwards.

Participant-B They did not like that and there was a lot of student protest about that. I had a lot of support even though there was a lot of protests, various people supported what I was doing, so we went ahead with it.

Participant-V I am open, somewhat, to making changes. Sometimes I have to hold the line.

Participant-P But, I know myself and I can't flick a switch on a new skill, so it'll be hard for me to do that.

Participant-B Well, it was a long process. Now it works fine. At the beginning we had a lot of startup problems I would say, because the faculty weren't used to the way we taught.

Participant-B Because I was doing it for the students, and I was trying to fudge around the facts [Inaudible] so I could do it for the students so they wouldn't be failed. That made it hard.

Participant-G When you start something new, it's always harder. But after a while, it might be easier or it might be no extra time, and maybe more rewarding too. Or maybe because it's more regarding, you actually don't mind spending a little extra time.

Participant-F I'm kind of technology averse in the classroom. I think that it can obscure more than it can illuminate.

Participant-G Helping enough faculty that understand that actually you can do this well without spending a lot more time. You can so this well without spending a lot more effort, at least not on a regular basis. I mean, when you start something new, it's always harder. But after a while, it might be easier or it might be no extra time, and maybe more rewarding too. Or maybe because it's more regarding, you actually don't mind spending a little extra time.

Changing incrementally

Participant-N So, it's kind of like a trial and error of finding different ways to explain things to students in every semester. Like, "Oh, let's try that." Like, "Oh, that worked really well. I should make a note of that so I remember to approach this explanation this way next time." Sometimes I do, sometimes I don't.

Participant-F That's the other thing is that if you try to change everything at once, you really paint yourself into a corner. That can really because a lot of personal anguish to the faculty that's taken that upon themselves.

Participant-V I have a particular way I like to teach but it can, I wanna be open. I want the way I teach it, I have a particular way but it's developing. I like to stick with it from semester to semester then kind of incrementally change it, I guess. I am open, somewhat, to making changes. Sometimes I have to hold the line.

Participant-V I'll make my PowerPoint slides, I'll pick out problems from the back of the book. I don't like to make drastic changes in the middle, I mean I haven't had that many semesters of teaching. I wanna be fluid, I wanna respond to them. I'll even ask them for feedback at certain points, after exams and whatnot.

Nervous

Participant-C For me, it is all still a very big learning process. And I'm very nervous about it.

Participant-P It was just too hard to sift through ... the way they taught it, like posting questions and trying to get ... posting responses anonymously.

Participant-C Initially, I thought that, "Maybe I should do all of these," and then I realized even when I started doing one of these, it's a lot of work and it's a lot of nervousness that goes into it.

Appendix D

Semi-structured interview protocol

We provide a sample interview protocol used for semi-structured interviews.

D.1 Interview Guide

- The interviews are planned to take around 45 minutes
- Anonymity of the interviewee will be protected
- Explain briefly the topic and focus of the study

D.2 Introduction

"Hi, I'm (name), thanks for taking the time to talk to us today! (note taker name) is primarily going to be taking notes, and may chime in at the end with some questions if we have time. Just to refresh your memory, we are working on a project about how physics instructors make changes in their teaching and how your teaching evolves over time, ultimately to find ways to support faculty like you better.

Did you get a chance to look at the consent form I attached in a recent email? Did you have any questions? Do you consent to participate in this research?

And just a reminder, I do have a variety of questions today, but just want to have a conversation to learn about you and your teaching.

I also wanted to confirm that you're okay with me recording this interview? While we are recording, do you agree to participate in this research study? Great, thank you again!

D.3 Faculty and department information

1. What's your title and role in your department?

2. How long have you been in the department?

3. Can you tell me about your previous teaching experience before this institution?

D.4 Information about their course

1. What courses are you teaching this term? (I'd like us to talk for a little while about how you're teaching one of your courses - Would you like to focus on this course, or is there a different course you've taught recently you'd like to talk about?)

2. OK, it's last week. I walk into your class. What do I see, what are you doing, what are the students doing? (Form of question: Can you tell us a bit about this course?)

    - Level, topic, number of students. (Maybe if there are multiple sections, and taught by others, or not?)
    - Have you taught this course before? (If yes: how many times before?)
    - How far into the term are you? [To find out whether this is early, middle or late in the term for the changes they are trying in that course. Might need to include whether course is semester or trimester]
    - How are you structuring the course?
        - How was that structure decided? [Level of autonomy in teaching the course]

D.5 New aspects of teaching

1. Is there anything new you're trying in your teaching this term?

    - Tell me about it.
    - How is this different from how you've taught before?
    - Or: If they aren't doing much new now: What about a time you were trying something new?

2. How did you decide to incorporate that into your teaching this term? Can you take me through the process?

    - What's your motivation for trying try this?
    - How did you go from having the idea to actually doing it in class?
    - Can you share more detail about X aspect of your process?
    - While you were/are planning this, what decisions did you find yourself making? How did you go about making those decisions? What guided you?
    - Note: What is the change that they are trying, and how they decided to make that change, will very likely be entangled in their replies, and that's fine.

3. Example follow-ups:

    - What prompted you to come up with this? Why did you decide to address X in this way? What motivated you to do this?
    - How did you come up with or learn about this idea? [where did info come from]
    - How did you go from having the idea to doing this in class? What happened next?
    - How did you develop the idea from there? (E.g., thinking on your own, experimenting, reading, talking to colleagues...) Did you come up with the ideas all at once? What was your process like?

- How did you (will you) figure out how to implement this idea? Are there any revisions or tweaks you're making from what you've read or tried before?
- How has this aspect been going so far this term? All good? Any surprises? Any downsides you're seeing?
- How do/will you know if/how well this is working? During the term? After the term?
  - Are there things you're looking for you'll use to help you decide how well it worked, and maybe if you want to keep using it in the future?
- What do you feel you need or would help to support you in making this change in your teaching?
- What was the role of X resource (e.g., your colleague)? Did you meet with them, how often, what did you talk about?

4. If it hasn't come up yet.
   - What have you struggled with in trying to implement new ideas in your teaching?

D.6 Course/teaching overall

If I don't feel like I'm getting a sense of what the course is like overall:

1. Can you tell me a bit more of an overview of how you're teaching this course?

D.7 Challenges

1. What are some aspects of how you're teaching this course that you are finding challenging?
   - What are some aspects of course planning that you are finding challenging?
     - Before the course started

  - On a week-to-week basis

2. Listen for a couple: For each follow up with questions such as:

   - What makes that aspect challenging? Can you give me some more context about it? Can you give me an example situation?
   - Has this been an issue in past courses you've taught? When/how did you start thinking this might be a challenge?
   - I'm curious about your process of thinking how to address this challenge.
   - Have you made any progress on addressing this challenge?
   - Example follow-ups:
     - What ideas have you had so far?
     - Have you thought of any other ideas?
     - How have you come up with those ideas? (e.g., talk to colleagues? online resources?) What supports you? Where does your info come from?
     - Why do you think that might be a good solution?
     - What info would help you decide what to do?
     - What info would help you convince your dept to do X?
     - How would you know if you had solved the issue?
     - Within the structure of your department, what's available to you to solve this challenge?
     - If challenge is really big, after asking them big-scale ideas for addressing: Are there smaller-scale instances of this challenge that you might able to make progress on? How would/do you approach that?

D.8 Resources

1. Any time resources come up

- Can you tell me more about how you use X resource/how X resource helps you?
- What kind of info are you drawing on/accessing? How are you using that info?
- Is this support supporting you the way you want, or are there places you feel frustrated or stuck?
- Are there other resources you draw on? Can you tell me how you use them?

2. If resources didn't come up yet:
    - What resources or supports do you draw on to help you with your teaching (this could include people, books, websites, conferences etc.)?
        - E.g., this semester?
        - Any new resources this semester?
    - Can you tell me how X resource helps you?
    - If we don't hear it: Have you ever looked into resources around how to teach?
3. What resources or info would you like to have?
    - Why do you need that support or info?
    - How would you use that info?
4. If PhysPort is mentioned, briefly ask:
    - How does PhysPort fit in? (How) do you use PhysPort in developing your teaching practice?
    - If they say something that seems helpful for our future study, float the question of whether we might be able to interview them again in the future, more focused on their PhysPort usage.

D.9 Future and/or past changes

If we got a lot out of the previous questions and don't have time for this, we can leave it out or be very brief.

1. Looking ahead, are there things you're thinking of changing about your teaching for next semester? Or is there any change you made recently that you're reflecting on?
   - Listen for which one they most want to talk about, or I think sounds most interesting, and pursue that one.
2. If future change:
   - What's making you think of that change?
   - How are you approaching it?
   - What info are you using/need/accessing? Where is it coming from? How are you using it?
3. If past change:
   - How did you feel that the teaching change went?
   - Is it something you'll try again in the future? Are there tweaks you'll make? How did you approach deciding this?

D.10 How learned to teach/departmental culture

1. How did you learn to teach like this? (Biggest influences?)
   - How has your teaching evolved over time (e.g., over your whole career) and why?
   - What do you feel like you're going for in your teaching? You're doing all these awesome things. Is there some underlying philosophy that's guiding you towards what you're doing?

  - Follow-up with why questions when they talk about what they are doing in the classroom.
  - Do you feel like your teaching philosophy or values have evolved over time? How so (and why)?
- Why is good teaching important to you? What's your motivation for your good teaching?
- Why did you decide to go to X institution? (Anything about teaching? Did you expect to teach this way?)

2. How were you taught while you were an undergraduate?

   - Why don't you teach the way you've been taught (if they don't)?
   - Zooming out: Can you tell me more of the big picture around why you teach the way you do?
   - Looking for their principles if they have them.

3. Departmental culture around teaching.

   - Who do you talk to about your teaching?
   - How often do you talk to other members of your department about their teaching? What do you talk about?
   - How much collaboration around teaching do you feel there is in your department?
   - How does your department decide who will teach each course?
   - What's your sense of how much your department/college/university values good teaching?
   - What would you say your department is like, in terms of culture around teaching?
   - What are aspects that are special/noteworthy about being at your community college/being at an —-? How do these influence your dept culture and/or your teaching?

- How do you feel your role as an adjunct influences your teaching?

D.11 Wrap-up

1. As we talk to lots of faculty, we're trying to honor and acknowledge the experience of people from different backgrounds. Could I ask you about your gender and ethnicity, and/or any other identities you have you'd like to share?

    - Another option: Are there barriers (or strengths) you've faced as a faculty member as a result of a part of your identity?
    - Back-up/what we might not ask:
        - What pronouns do you use?
        - Do you have any marginalized identities, like race, ethnicity, or religion, that you feel are important to your experience as faculty?

2. At 50 min: I'm mindful of your time; do you need to go right at X time?

3. Before we close, is there anything you'd like to add, or anything we should have asked you about, but didn't?

4. Maybe explain what we're doing, let them know we're doing research, will write paper, will send.

5. Are there any questions that you have for us?

D.12 Closing

Personalized closing about how what they are doing is really cool and interesting, and potentially how what they've shared with us is really going to helpful for us improving PhysPort. "Thank you so much for your time! This was very useful and we really appreciate it." [If they seem uncomfortable about how the interview went, we could offer to delete all or part of the recording if they would like.] Follow up with an email thanking them again for their time shortly afterwards.

Appendix E

Participant Consent form

Title of Study: PhysPort's impact on teaching practice

This is a research study. Please take your time in deciding if you would like to participate. Please feel free to ask questions at any time.

Introduction

The purpose of this study is to better understand what kinds of support faculty have (and need) when they make changes to their teaching. You are being invited to participate in this study because you recently made a change to your teaching or are considering upcoming changes.

Description of procedures

If you agree to participate, your participation will consist of this interview, which will last approximately one hour. During the study we will ask you to respond to written and verbal questions related to your experiences of trying new teaching methods or activities in physics classes. You will often be asked to explain the reasoning behind your answers to the best of your ability. The interviews will be videotaped and/or audio taped.

Risks

There are no foreseeable risks from participating in this study, other than your inconvenience and possible discomfort at answering questions involving assessment and/or related topics.

Benefits

By participating in this study you will spend time thinking about teaching methods and/or related topics which may benefit your overall understanding of them. It is hoped that the information gained in this study will benefit society by providing valuable information about ways to support faculty in teaching physics.

Costs and compensation

You will not have any costs from participating in this study.

Participant rights

Your participation in this study is completely voluntary and you may refuse to participate or leave the study at any time. If you decide to not participate in the study or leave the study early, it will not result in any penalty or loss of benefits to which you are otherwise entitled.

Confidentiality

Records identifying participants will be kept confidential to the extent permitted by applicable laws and regulations and will not be made publicly available. However, federal government regulatory agencies and the Institutional Review Board (a committee that reviews and approves human subject research studies) may inspect and/or copy your records for quality assurance and data analysis. These records may contain private information.

To ensure confidentiality, the following measures will be taken: Your interview tape will be identified by a code number, and may be retained indefinitely for reference. However, it will only be seen/heard by Dr. Sayre and her collaborators. Neither your name nor information identifying your individual interview will be disclosed to anyone else. A list of participant names along with their corresponding code numbers will be kept with the data. Data will be kept in locked rooms and/or on password-protected computers. Small excerpts of your interview may be included in research presentations, but no other identifying information will be provided in any presentation. If data that you provide are published, your identity will remain confidential.

Questions or problems

You are encouraged to ask questions at any time during this study. For further information about the study, please contact Dr. Eleanor Sayre at esayre@ksu.edu or at the following phone number: 785–532–2124.

If you have any questions about the rights of research subjects or research-related injury, please contact the Research Compliance Office, at comply@ksu.edu or at the following phone number: 785–532–3224.

Consent

I have read the above description of the research. Anything I did not understand was explained to me by the investigator conducting the interview, and I had all of my questions answered to my satisfaction. I acknowledge that I may save a personal copy of this form on my computer. I affirm that I am at least 18 years of age or older. By signing up for an interview using the online scheduling tool, I indicate that I agree to participate in this research.