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Analyzing the Mindsets and Behaviors of Introductory Physics Students through the Lens of Intellectual Humility

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Analyzing the Mindsets and Behaviors of Introductory Physics Students through the Lens of Intellectual Humility

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A senior thesis submitted to the Honors Program in partial fulfillment of the requirements for the Bachelor of Science degree with a Major in Mathematics-Physics
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Abstract

Students often enter the physics classroom with intuitive conceptions drawn from real life experiences or former coursework, and may be hesitant or reluctant to re-evaluate these mindsets in favor of formally instructed knowledge. The goal of introductory physics courses is not only to teach and expose students to new content, but also to cultivate students’ ability to reason through and derive content knowledge through personal inquiry. This scientific process necessitates one’s abilities to be open-minded in terms of hearing evidence that contradicts his or her personal opinion, to be willing to discard any original misconceptions in the face of such alternative evidence, and to identify and pay appropriate attention to one’s academic limitations. Such a mindset is indicative of the quality of Intellectual Humility (IH), defined as “the owning of one’s limitations.” In this report, we present the results of a thesis study in which Intellectual Humility surveys, written reflections, and classroom observations were collected for students in both a traditional, lecture style physics course and an interactive, problem solving based physics course. Analyzing these data allowed us to examine the role of Intellectual Humility in the context of an introductory electricity and magnetism course and better understand student perspectives and interactions in these settings.
Chapter 1: Introduction

In this chapter, we discuss the specific problem that this study addresses and the field of physics education research. We also provide details relating to the phenomenon of interest and provide the purpose of and justification for our work.

Statement of the Problem

A serious problem in college-level Science, Technology, Engineering, and Mathematics (STEM) courses is the high drop-fail-withdrawal rates that primarily occur at the introductory level. For the physics discipline in particular, students often deem the subject one of unparalleled difficulty and frequently enter the physics classroom with a lack of confidence in their academic capabilities (Sharma & Bewes, 2011). As such, it is crucial to develop and study new ways of teaching physics that will provide students with a positive learning experience that both retains their interest in STEM fields and allows them to be successful in these courses. The studies that address how instructors may respond to diverse student reasoning difficulties in physics comprise the field of Physics Education Research (PER).

There are multiple aspects of learning physics that oblige PER studies to improve teaching methods. Mainly, students have a hard time grasping physics concepts: “people spend considerable time and effort constructing a view of the physical world through experiences and observations, and they may cling tenaciously to those views – however much they conflict with scientific concepts – because they help them explain phenomena and make predictions about the world” (National Research Council, 2000, p. 179). This is to say that students often enter the physics classroom with intuitive conceptions drawn from real life experiences or former
coursework, and they may be hesitant or reluctant to forego these mindsets in favor of formally instructed knowledge. The goal of introductory physics courses is not only to teach students new content, but also to cultivate students’ abilities to reason through and derive content knowledge through personal and collaborative inquiry. PER studies tend to the problem of how to best teach physics students with these goals for the students in mind.

**Phenomenon of Interest**

As previously mentioned, students in introductory physics courses often hold firm physical conceptions based on their experiences in both real life and in their education. Introductory courses must serve as platforms in which students gain scientific skills not only related to understanding the subject’s material, but also related to collaboration and engagement with peers. Moreover, the scientific process requires one to be open-minded in terms of hearing evidence that contradicts his or her personal opinion, to be willing to discard any original misconceptions in the face of such alternative evidence, and to identify and pay appropriate attention to one’s academic limitations during academic conversations. Such a mindset is indicative of the quality of Intellectual Humility (IH), and entails not only a willingness to revisit misconceptions about the course content, but also being open to learning in different classroom environments. One may prefer and be used to studying as an individual and attending large lectures wherein they are not required to solve problems or actively engage themselves during class time. But the reality is that beyond the scope of higher education, jobs and professional interactions necessitate collaborative and argumentative social skills. As such, students must be both open and able to negotiate academic conversations in an interactive learning environment. Such behaviors that occur within groupwork oriented academic settings for introductory physics
courses – in addition to the preferences and mindsets of the students – shall be the focus of our study, as we gauge students’ learning experiences through the lens of Intellectual Humility.

**Background and Justification**

We are certainly not the first to identify the need for more active teaching styles and bring attention to the current state of freshmen or entry-level students as withholding misconceptions and close-mindedness in an academic setting. Researchers have made a strong case for deep learning when students in the classroom are not stagnant and inactive listeners, but are actively engaging participants that seek to make sense of their learning environment. Further, science education researchers aim to involve students in the classroom with practices of “asking questions, developing and using models, carrying out investigations, analyzing and interpreting data, constructing explanations, and engaging in argumentation” (National Academies of Sciences, Engineering, and Medicine, 2018, p. 145). As we will see, all of these skills are embedded in the epistemological virtue of Intellectual Humility.

In the discipline of physics in particular, much has been done to tend to these practices, the most transformative of which involves complete reconstruction of physical classrooms and innovation of demonstrations, labs, and course activities. Such attempts to create what scholars deem “Studio Physics” classrooms reorganize the physical layout of the classroom to foster groupwork and discussions, and actively integrate problem solving sessions and hands on labs with instructor-led lectures.

While these reforms are certainly plausible and feasible in terms of physically orienting students toward active engagement and group collaboration during class time, there is still a need
to hear what students actually perceive and enact in these settings compared to traditional classrooms. A concept that has recently attracted more attention in the philosophy community is Intellectual Humility and we propound that this worldview may yield imperative insights into facets of the introductory physics classroom, as we have just described how components of engagement, reconsidering one’s mindset, and admitting one’s limitations all come into play in an active learning setting.

**Deficiencies in the Evidence**

The reformation of introductory physics classrooms to tend to the collaborative nature of the world has been an ongoing area of physics education research. However, our literature review did not render any empirical studies with our view that Intellectual Humility in particular may afford a new and beneficial perspective of the physics classroom. Applied to the physics discipline in particular, we seek to apply this philosophical lens in order contribute to the literature an empirical look at the role of Intellectual Humility in the educational setting of a science classroom.

**Purpose of the Study**

The purpose of this study is to address the problem of optimizing in-class collaborations and content knowledge acquisition for students by analyzing how students both behave and describe their learning experiences in an introductory physics classroom. Through the lens of Intellectual Humility, we seek to assess the mindsets and in-class behaviors of introductory physics students in both a traditional, lecture style setting and a more interactive, problem solving based course at a large public university in the northeast.
Chapter 2: Literature Review

In this chapter, we first discuss the theoretical framework of Intellectual Humility, including its historical context and a synthesis of previous studies related to the concept. We also provide a background about the teaching and learning of physics in particular to address the following: what teaching styles have been formulated and executed to tend to the various ways in which students learn science? Finally, we identify limitations within the literature and discuss the need for our study.

**Intellectual Humility**

Intellectual Humility, a virtue comprised of intellectual confidence and awareness of fallibility, has been a rising subject of research in the fields of philosophy and psychology. With a growing need to stimulate academic confidence and open-mindedness across many disciplines, research on Intellectual Humility in education is only at its beginning stages and further exploration is in demand (Spiegel, 2012). This study seeks to use Intellectual Humility as a basis for investigating the learning experiences of physics students who actively engage in academic conversations in the classroom.

We have chosen to use the theoretical definition by Whitcomb et al. (2017), which states that Intellectual Humility is the “owning of one’s limitations.” This is to say that all students have limitations such as knowledge gaps and deficits in learning capabilities, but an intellectually humble student will maintain a cognitive awareness of such limitations and effectively own them in his or her pursuit of truthful knowledge. Whitcomb and his colleagues put forth 19 predictors for an intellectually humble individual, which can be found in Appendix A. These are important
in that they relate to both mindsets and observable actions, and may be evident in an educational setting such as the physics classroom. To summarize, these predictors maintain that an intellectually humble individual considers the ideas of others and reconsiders his or her ideas in the face of such ideas if truthful, seeks help from others or external sources when an academic limitation calls for such an action, and holds the appropriate level of confidence in his or her knowledge.

Intellectual Humility also involves open-mindedness toward others’ knowledge and the ability to effectively monitor oneself during academic argumentation (Kidd, 2016). Kidd further states that argumentation, in which conversers provide support for their personal convictions, may cultivate traits such as Intellectual Humility. In a classroom, especially a science classroom, it is critical that students defend their own methods and standpoints while weighing the arguments of others. The self-perceptive facet of self-monitoring and remaining humble during academic discussions and arguments prompts students to productively collaborate and empathize with their peers (Hoyle, 2016).

It is important to elaborate on the fact that Intellectual Humility is an epistemic virtue. Hill (2016) frames virtues as those concepts or traits that contain six qualities: integrates ethics and health in human flourishing, involves embodied traits of character, serves as a source of human strength and resilience, is embedded within a cultural context and community, is linked to a sense of meaningful life purpose, and is grounded in the cognitive capacity for wisdom. This is essential to the role of Intellectual Humility in educational settings, as students’ in-class behaviors and mindsets influence their physical and mental search of truth. In the pursuit of epistemic goods such as knowledge, Roberts and Wood (2003) argue that intellectually humble
individuals act in ways contrary to vain or arrogant individuals. Tanesini (2016) likewise categorizes Intellectual Humility as a grouping of internal attitudes towards one’s own cognitive state and limitations, comprised of both self-acceptance and modesty. In conjunction with Roberts and Wood, this is to say that Intellectual Humility lies in between the traits of servility and arrogance.

Intellectual Humility may additionally be considered a subdomain of the virtue of humility in general, as proposed by Davis and colleagues (2016) in their empirical study of undergraduates in a psychology course. Applying factor analysis to student responses to various general humility and Intellectual Humility scales, the authors determined that Intellectual Humility is a distinct trait in which people are justified negotiators of ideas. Frostenson (2016) theoretically explored the role of general humility in the business and economics context, suggesting that the virtue “reflects the cooperative and social nature of business” as well as the self-interest and self-efficacy components of engaging in interdependent business negotiations. As mentioned in the introduction, real-world interactions require an appropriate approach to intellectual conversations and humility involves self-awareness during such discussions. Not only in corporate settings, but also in classrooms, do people need to adequately and appropriately retain confidence in their convictions and act accordingly.

Nevertheless, we were able to find only a few empirical studies related to Intellectual Humility, and only one of them takes place in an educational setting. Deffler et al. (2016) compared participants’ completion of recognition tasks with their responses to a general humility scale; they found that intellectually humble individuals may be more likely to retain and pay attention to new information. This may also align with the role of Intellectual Humility in the
educational sphere, as students must learn and correctly apply new material to given problems and situations. In a more recent study investigating the role of Intellectual Humility in learning, the authors found that Intellectual Humility relates strongly to a proper assessment of one’s own knowledge, collaboration within learning environments, and intellectual openness (Krumrei-Mancuso et al., 2019). Multiple survey implementations allowed the researchers to link Intellectual Humility to both a higher self-awareness of one’s knowledge and possession of more general knowledge. Further, the authors suggest that Intellectual Humility influences directly the thinking styles, intrinsic motivation, and interpersonal dispositions of students. As such, these studies point to the potential role of Intellectual Humility in both academic conversations and content knowledge acquisition.

Teaching and Learning Physics

Beginning in the 1970s, teachers and professors in the field of physics recognized the need to address student difficulties and misconceptions. Although faced with a bit of skepticism from social scientists during the earliest studies, more and more tenure-track faculty have pursued lifelong careers in PER and retain firmly the need for such work (Cummings, 2011). The rise of groups of professional scholars such as the American Association of Physics Teachers (AAPT) and publications such as the Physical Review Physics Education Research Journal also illustrate the demand for reforming the way we teach and learn physics in modern society.

Physics Education Research has led to a large reformation of traditionally styled courses and pushed toward lower enrollment, interactive classroom settings to teach college level physics. Traditional physics courses are taught in stadium-style lecture halls with focus on the
instructor and very little peer to peer engagement during class time. Figure 2.1 shows a typical classroom for this teaching style at the University of Connecticut. There are a large number of students in the classroom, and the lecturer is the primary transferrer of information.

Figure 2.1. An example of a traditional course lecture setting at the University of Connecticut. (Credits/Jason Hancock)

Contemporary science learning theories rely less on the old-school objective of simply wanting students to learn the content, and more on students actively engaging in classroom activities, asking questions of their peers and instructors, and revising original claims based on challenges from peers. Facilitating these actions in an interactive classroom comprise the theory and educational reformation known as “active learning.” The premise of active learning is that students express reasoning through group problem solving activities, reflect on their own problem solving approaches, and use actual physical systems in the learning process (Meltzer & Thornton, 2012). Time spent in the classroom emphasizes hands-on contact with physics problems and active engagement with peers to enhance learning. For physics in particular, active learning proves a beneficial aspect of classroom instruction, and entire manuscripts devoted to
laboratories that utilize active learning have been published and implemented (Sokoloff et al., 2011). In active learning environments, students are encouraged to critique and provide feedback to their peers and actively reason through laboratory assignments or problems, which is typically difficult to achieve in high-enrollment lectures (Deslauriers et al., 2011). In an empirical study comparing introductory mechanics courses, Hake (1998) found that students in an interactive engagement course performed better on conceptual assessments than students in traditional courses. Hence, interactive classroom settings may offer better learning opportunities for students than a traditional lecture setting. Figure 2.2 portrays a typical classroom setting that affords interactive learning at the University of Connecticut, as the triangular tables with shared computer screens and whiteboards around the perimeter of the room facilitate groupwork.

*Figure 2.2. An example of an interactive course classroom setting at the University of Connecticut. (Credits/Garrett Spahn ’18 (CLAS)/UConn Photo)*
Studio Physics, first implemented by Professor Jack Wilson at Rensselaer Polytechnic Institute (Wilson, 2002), is a method of teaching in which students actively engage in groupwork and lab-related activities. In this way, the class “eliminates the synchronization problem of separate lecture and lab sections and replaces much of the less effective lecture time with active learning” (Beichner, 2014, p. 14). Studio Physics also makes use of the physical setup of the classroom: the courses take place in rooms with tables and whiteboards that foster collaboration and facilitate access to equipment for hands-on activities (Beichner et al., 2007). The site of this study is currently constructing more classrooms specifically for this interactive teaching style, to be used for a large number of introductory courses starting in fall semester of 2019. For the purposes of this paper, the courses we observe are not yet fully transformed and integrated into Studio classrooms and assignments, so we will refer to these Studio-like- courses simply as interactive learning environments.

In addition to behaviors during active learning and negotiating academic conversations, physics students’ mindsets play a critical role in the learning process. One’s beliefs, values, interpretations, and perceptions greatly impact how one acts upon their surrounding learning environment (Dweck, 2013). It is important that students approach physics, as well as any other discipline, with appropriate attitudes and epistemological mindsets toward the material. Domert et al. (2012) investigated student mindsets toward understanding physics equations and found through qualitative interviews that students generally believe they only need to identify the appropriate symbols and quantities and use the right equation to succeed in physics. As the authors suggest, there arises a need to further assess student mindsets toward learning physics and appropriately address the lack of epistemological thought put toward the discipline. In a previous study, students in an honors introductory physics course reflected weekly on what they
learned and how they learned it. Higher performing students were found to hold more favorable epistemological beliefs and practice more self-regulatory behaviors, as seen in their written responses (May & Etkina, 2002). This finding suggests the importance of self-reflection in both cultivating appropriate mindsets and beliefs toward learning, as well as learning physics material.

As we have seen up to this point, there seems a decently large role for Intellectual Humility to play in learning sciences. Encouraging students to be open to hearing the opinions of others, to be willing to revisit and revise their own mindsets, and to effectively collaborate with peers is in line with both the virtuous pursuit of knowledge and the learning theories that drive teaching in STEM fields. The lack of work done to relate Intellectual Humility to the domain of physics prompts us to explore the potential implications for instruction and learning that this virtuous epistemology may hold.

**Research Questions**

The overarching aim of our study is to address the following central research question: *What are the mindsets and in-class behaviors of introductory physics students?* As indicated in the literature review, a closer look at such mindsets and behaviors with the philosophical perspective of Intellectual Humility may direct our attention to particular aspects of students’ learning experiences. The three specific research questions that guided this study were:

1. How do students’ self-reports about their Intellectual Humility, under a limitations-owning perspective, compare for students enrolled in a traditional class format and those in an interactive class format of an introductory electricity and magnetism course?
2. How do students discuss and reflect on their learning experiences in both an interactive and a traditional introductory electricity and magnetism course, through the lens of Intellectual Humility?

3. How do students in both an interactive and traditional introductory electricity and magnetism course embody dimensions of Intellectual Humility in the classroom?
Chapter 3: Methodology

Aim of the Study

This study aims to investigate the mindsets and behaviors of introductory physics students through the lens of Intellectual Humility. By looking at survey responses, written reflections, and in-class observations from a traditional and interactive classroom, we seek to both gauge the general perspectives of students at this level and dig deeper into the effects of different learning environments.

Qualitative Research Approach

In order to address the research questions through an appropriate research design process, it is necessary to identify a guiding philosophical framework that directs the methodological approach and subsequent analysis of the data. Educational research often occurs under the framing of social constructivism in that the classroom is home to interpersonal communications and experiences that comprise reality. Through qualitative inquiry, constructivist researchers focus on the specific environments in which people live and work to understand the cultural settings of the participants (Creswell, 2007). That is, the participants of a study create their own subjective meanings of reality from the cultural norms of their specific social surroundings (Crotty, 1998). Sometimes used interchangeably with the theoretical perspective of interpretivism, social constructivism also relies on the idea that those who experience the same phenomenon hold different interpretations or realities (Merriam and Tisdell, 2016). The goal of constructivist researchers, then, is to construct and disseminate knowledge based on these multiple and separate individual realities that belong to people in a particular social context.
In regard to the purpose and research questions of this study in particular, the theory of social constructivism is necessary to understand the experiences and realities of students in introductory physics courses. Adhering to a specific theoretical definition will enhance the consistency of our analysis and direct the researchers’ construction of student subjectivities. Both social constructivism as an overarching basis of our qualitative design and the previously described theoretical framework for Intellectual Humility align with our research questions and guided our methodology and methods of data collection, described in the following sections.

**Participants**

Since our focus is on introductory physics courses in particular, the participants for this study were students who were enrolled in two different introductory electricity and magnetism courses for the fall 2018 semester at a large public university in the northeast. One course was a traditional, large enrollment, lecture oriented physics course in which students attended three 50-minute lectures in a stadium-style hall and one 3-hour lab each week. The lecturer was a professor in the Physics Department, while graduate students instructed the lab sections. Each lecture section of this course contained about 120 students, and each lab section contained about 18 students. This course was intended for engineering majors, so most if not all of the students were engineering majors. We will refer to this classroom setting as the “traditional course.”

The other course was a more interactive, smaller enrollment physics course intended for students majoring in physics. About 30 students were enrolled in this course, which took place during three 2-hour time periods each week. Lectures, engaged discussions, problem solving sessions, and quantitative laboratory sessions were all integrated into these time slots and were facilitated by a professor in the Physics Department and a few graduate student teaching
assistants (TA). The course took place in a rectangular classroom with whiteboards and screen projectors located along all of the perimeter walls. There were four triangular tables with three seats along each side and one computer per side, such that each table seated 9 students and had three computers. For lab and group purposes, this seamlessly formed groups of three students that were already aligned toward one workspace on the computer screen in front of them. We will refer to this classroom setting as the “interactive course.”

It is important to note that the two lecturing professors taught similar course content using similar slide shows and syllabi. Although the two courses contained students in different majors, and there was a large difference in the number of enrolled students, the two classes are comparable to the extent that the students were all enrolled in an introductory course learning similar content.

The following were collected from the consented participants: Intellectual Humility surveys at both the beginning and end of the semester, two rounds of open-ended survey reflections, and in-class observations by the researcher.

Data Collection Tools

As we have chosen to pursue an investigation of Intellectual Humility in a classroom environment, the question then arises how one may measure a student’s level of Intellectual Humility. Multiple researchers have created and tested the validity of potential surveys that could serve this purpose, including a 22-item survey by Krumrei-Mancuso and Rouse (2015). They reduced their questions to four categories or dimensions, including independence of intellect and ego, openness to revising one’s viewpoint, respect for others’ viewpoints, and lack
of intellectual overconfidence. More recently, some of the authors of the original Whitcomb theoretical framework collaborated with colleagues from the field of psychology to develop and validate a 12 question, Likert-scale style Intellectual Humility survey (Haggard et al., 2018). Groups of four survey questions make up each of three dimensions of Intellectual Humility: love of learning, appropriate discomfort with limitations, and owning intellectual limitations. For the purposes of this study, we will use the latter survey, since it more closely aligns with our theoretical groundings. This survey uses a 5-point scale, ranging from 1 = strongly disagree to 5 = strongly agree. An example of a statement related to love of learning is: “I care about truth.” On the other hand, an example of a statement related to appropriate discomfort with limitations is: “When I know that I have an intellectual weakness in one area, I tend to doubt my intellectual abilities in other areas as well.” Finally, an example of a statement related to owning intellectual limitations is: “When someone points out a mistake in my thinking, I am quick to admit that I was wrong.” A full list of the survey statements and their corresponding dimension can be found in Appendix B.

Procedures

All methods of data collection and analysis have been approved by the Institutional Review Board (IRB) under Protocol H18-023. Per the requirements of the IRB, students were asked to be a part of the study on a voluntary basis and only upon their informed consent to participate. All data sources were anonymous in the sense that the identity of the participants could not be determined by anyone, even the members of the research team, since we used a coding scheme to collect and store the data. Anonymity was also maintained on written reflections using the codes. Since only excerpts of the full reflections are reported, and given the
generality of the topics the students were reflecting on, participants might be able to relate to certain quotes but not identify themselves in them. Many reflections indicated similar preferences using similar vocabulary, so it is impossible for the participants themselves, readers of the excerpts, or the research team to connect reflections to a particular student. Each student was assigned a code based on demographic information such that it would impossible for the researchers to match a code to a specific participant. We collected three forms of data for those who consented to the study, including Intellectual Humility surveys at both the beginning and end of the semester, two rounds of open-ended survey reflections, and in-class observations by the researcher. Table 3.1 shows the number of consented students and amount of each data source we collected, broken down by the course type for comparison. Aside from the number of classroom observations, which are enumerated by the number of sessions we observed, all N values represent the number of students who completed the data form. Since we were limited in the number of students enrolled in the interactive course, we chose to only use two laboratory sections of the traditional course, such that there was a similar amount of data for each learning environment.

Table 3.1. Number of data sources for each collection method.

<table>
<thead>
<tr>
<th></th>
<th>Traditional Course</th>
<th>Interactive Course</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consenting Students</td>
<td>31</td>
<td>23</td>
</tr>
<tr>
<td>IH Pre-Survey</td>
<td>30</td>
<td>18</td>
</tr>
<tr>
<td>IH Post-Survey</td>
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<td>7</td>
</tr>
<tr>
<td>Reflections 1</td>
<td>12</td>
<td>24</td>
</tr>
<tr>
<td>Reflections 2</td>
<td>17</td>
<td>20</td>
</tr>
<tr>
<td>Classroom Observations</td>
<td>1</td>
<td>4</td>
</tr>
</tbody>
</table>
As described in the previous section, our measure of Intellectual Humility was based on a previously developed and validated survey (Haggard et al., 2018). Collecting these survey responses tended mainly to our second research question, for the results indicated how introductory physics students as a whole are currently thinking about and conceptualizing their academic environments in relation to Intellectual Humility. In order to both compare the students in the traditional versus the interactive course and compare students’ change in responses over the course of the semester, we administered the survey to all consented students at both the beginning and the end of the semester. The survey was administered online via Qualtrics and students selected their agreement with the 12 survey statements on a 5-point Likert scale. As seen in Table 3.1, not all students completed one or both surveys.

In between the two administrations of the survey, we asked students to fill out two open-ended written reflection questionnaires related to their classroom preferences, behaviors, and mindsets. The questions we asked can be found in Appendix C, and were aimed at our first and third research questions. The first round of questions focused on how in-class resources influence student engagement in groupwork, and the second round of questions focused on how students interact about topics about which they are not completely certain. Asking participants to elaborate on what alters their in-class engagements, what peer attitudes help or hinder their academic conversation, and how they rectify inconsistencies or wrong approaches was important in assessing how students both embody concepts related to Intellectual Humility and reflect on their learning experiences.

Throughout the semester, we completed in-class observations of both types of courses. Through careful field notes about students’ behavioral gestures and verbal communications in a
live classroom setting, we were able to gain insight into how students embody aspects of Intellectual Humility in the physics classroom (relevant to the second research question). We observed lab sections of the interactive course and the lab sections of the traditional course in order to compare student dynamics during similar types of groupwork. Notes about where students performed certain actions, what they said to each other or to the professor, and some researcher interpretations were recorded during observation sessions.

Data Analysis

The Intellectual Humility survey results were extracted from Qualtrics as Likert responses in word form: “strongly disagree,” “somewhat disagree,” “neither agree nor disagree,” “somewhat agree,” and “strongly agree.” To facilitate both our statistical interpretation of the surveys themselves and our comparison of survey results to the reflections and observations, we converted these responses to numerical results on a 5-point scale. As indicated in the survey’s development and validation paper, we quantified each question such that 5 indicated the most favorable response and 1 indicated the least favorable response, according to the theoretical framework and predictors of Intellectual Humility. Following this management of the survey data, we proceeded with a few statistical tests. We first determined basic descriptive statistics for the pre-survey responses of all students in both courses combined to gain a general scope of how introductory physics students are thinking about constructs related to Intellectual Humility. We then found basic descriptive statistics for and performed independent samples t-tests on the pre-surveys of the two courses separately, in order to gauge the comparability of the students in each class. We also found basic descriptive statistics for and performed independent samples t-tests on the pre-survey and post-survey responses of each course separately. These procedures
allowed us to compare how students in the different classroom settings self-identified with each of the dimensions of Intellectual Humility both before and after engaging in the two distinct teaching styles. On top of quantitatively examining the surveys as a stand-alone data source, we used statistical results within the three dimensions as a basis for comparison when we qualitatively analyzed the student reflections. This synthesis is presented in Chapter 5.

Students hand wrote responses to the reflection questions, so we transcribed them into Excel to ease the coding process and organize in one place each students’ responses to both questionnaires. To address the first research question, we began by open coding the student written reflections; this is as a preliminary step toward understanding concepts within the data in qualitative data analysis. By setting aside personal subjectivities and existing theories, the researcher seeks to inductively extract codes, categories, and themes from the data. The process of open coding involves converting the raw data to a clean format, engaging in a close reading with the text, and creating and defining preliminary codes (Thomas, 2006). In the final stage, the researcher assigns a word or short phrase to individual pieces of text to capture the core concepts within the data. Grbich (2013) puts forth some important questions that a researcher may consider when applying open codes: “What is going on here? Why is this being done?” (p. 83).

Upon breaking down qualitative data into preliminary codes, we continued with an inductive analysis, which allows researchers to examine and compare the main concepts evident in the data (Saldana, 2016). Observing similarities, differences, and other relationships amongst first round open codes directs the researcher to proceed with a certain second cycle coding process, and may even give some insight into broader categories or themes. Grbich (2013) emphasizes that open codes should involve questioning the data and consistently critiquing the
data. By doing so, the researcher may also engage in “induction, deduction, and verification,”
during which specific instances within the data are cross-checked with one another and
generalized as inferences (Grbich 2013, p. 83). Although the open codes allowed for the data to
speak for itself without much researcher interpretation, our study necessitated a second cycle of
coding in which the lens of Intellectual Humility was applied to the codes in a more deductive
manner. This process took the form of directed content analysis, in which pre-existing theory
and prior research guides the creation of codes and categories (Hsieh & Shannon, 2005). We
condensed and named our open codes to reflect certain aspects of Intellectual Humility, while
still preserving what the students voiced, and created a refined definition of each code. We then
recognized larger categories that described the codes, and in this categorization each code only
fit into one category. To ensure reliability of these codes and their definitions, two of the
researchers separately coded a portion of the reflection responses and reached a suitable level of
agreement. Together, we refined the codebook for clarity in the names and definitions and
ensured that the codes and categories were mutually exclusive. The emergence of the main
categories and the placement of the particular codes into such categories addressed the question
of how students think and talk about elements of Intellectual Humility as related to in-class
experiences.

The in-class observations were similarly open coded and, upon recognition that the field
notes were of similar content to the insights within the student written reflections, were coded
with the same refined codes as the reflections. Relating the two data sources via a common
coding scheme then allowed us to compare and contrast the content within the reflections to what
is actually happening in the two different academic settings in terms of both physical and verbal
behaviors during collaborative conversations.
From these three separate sources of data, and in our analysis procedures that compare them to one another, we hope that this mixed methods study begins to answer our three research questions and provides a well-rounded and largely encompassing data set that explores the role of Intellectual Humility in the introductory physics classroom. Grounding our results in the theoretical underpinnings of Intellectual Humility and science learning theories will be essential in relating our findings to existing research while also opening a new lens of analysis for PER work in addition to education research in other disciplines.

**Ethical Considerations**

All data were encrypted and stored on password-protected computers accessible only to the research team. Only computers in possession of the research team hosted such files. These computers had password protection and files were encrypted to prevent access by unauthorized users. Each participant of this study was assigned a code and all forms of data in this study were labeled with the appropriate code. In the case of observations, it is important to note that the observer did not have access to full names of participants; thus, pseudonyms were assigned to help record what was observed. In addition, the results presented in this thesis are in aggregate form and where appropriate use the pseudonyms. The nature of the collection and storage process was such that no identifiable information was available for this study and the dissemination of its results.

**Trustworthiness**

The main form of trustworthiness in this study is data triangulation. According to Merriam and Tisdell (2016), “triangulation – whether you make use of more than one data
collection method, multiple sources of data, multiple investigators, or multiple theories – is a powerful strategy for increasing the credibility or internal validity of your research” (p. 245). We collected three different sources of data to determine how Intellectual Humility comes into play in an introductory physics classroom: an Intellectual Humility survey, reflection questionnaires, and in-class observations. While the student participants themselves responded to the survey and reflection prompts, the researcher performed the in-class observations. In this way, we were able to compare and corroborate evidence from multiple sources and individuals, such that the students’ mindsets and behaviors were analyzed most appropriately and accurately. Additionally, the findings section includes excerpts from the corpus of the data that help to inform the reader and support potential transferability of the research findings (Patton, 2015).

**Potential Research Bias**

My research experience as an undergraduate may influence how I view both the physics classroom and the student participants. All of the research I have done at the University of Connecticut has pertained to improving education through Intellectual Humility. I have been an active participant in an Intellectual Humility in Education working group, with graduate students and professors who are working to integrate Intellectual Humility into the classrooms of different disciplines. One of the professors in the group is Heather Battaly, a co-author of the Whitcomb et al. (2017) article used as the theoretical framework for this study. My conversations and interactions with experts and proponents of Intellectual Humility, as well as my work in the field of Intellectual Humility in education, thus presents a potential bias in that I see value and potential in Intellectual Humility being taught to and embodied by physics students to improve their learning; hence, this might have influenced how I interpreted the data.
I also carry a bias in that I have gone through almost all of the undergraduate course requirements for physics majors and have been exposed to different types of professors and modes of teaching. I personally prefer a more interactive, problem solving based instructional method as compared to traditional lectures and individual work, so I may hold certain attitudes when judging or analyzing different types of classrooms within the study.

In researching topics of physics education, my experiences as a student have shaped my views of the domain and thus sculpted my creation and interpretation of such studies. Although my identity and experiences may make my analyses susceptible to certain biases, I have kept these factors in mind throughout this study such that any subjectivity is both minimized and clearly conveyed to the reader.

Limitations

The main limitation of this study is the sample size. Since only one section of about 30 students were actively enrolled in the interactive course, this limited the size and scope of our study in terms of the amount of survey responses we could collect. In terms of quantitative analysis, the outcomes of our statistical tests would be better substantiated by a larger sample size. Our restricted number of survey responses may narrow the spectrum of perspectives we saw in the data and restrict the generalizability of our findings; however, we still believe that this exploratory study yields important insights into the mindsets and behaviors of introductory students.

The main limitation pertaining to the student written reflections about their learning experiences is that we did not have access to further details about the students who participated
in the study. A richer description of or background information about whose voice we were analyzing would have enabled additional connections between participants and allowed us to attribute what they had to say to underlying qualities they may have had, but we were not aware of. For example, the fact that we did not have information about these students, beyond what they wrote in reflections and responded in surveys, limits the meaning of the reflections and the scope of our thematic analysis. The voices of the students in this study were still valuable in answering the research questions; however, additional knowledge, for example about their educational background, age, values, other academic and personal experiences in the course, may have allowed us to draw even more relationships among the reflections and derive further meaning from each participant. This information could have been accessed through interviews with the students; however, time and resource constraints prevented us from being able to incorporate these in the study design for this thesis. Nevertheless, this exploratory study still gives important insights into the mindsets and behaviors of introductory physics students, to the extent of their responses to the forms of data collection.

A final limitation, and one that could be easily resolved in future work, is our restricted insights into the professor’s perspectives. We did not collect any data from the instructors of the courses such that the learning experiences of the students could be put into their viewpoint. This would be an interesting addition to our study because the two different courses from which we collected data were taught in very different manners and in distinct classroom settings. An instructor’s insights into how the learning environments may have contributed to student responses and in-class actions as related to Intellectual Humility would certainly enhance our findings.
Chapter 4: Findings

In this chapter, we present the findings corresponding to each research question according to the data analysis procedures previously described for the three main sources of data: Intellectual Humility surveys, written reflections, and in-class observations. We objectively interpret the students’ responses in order to most accurately portray the ideas of current students.

Self-Reported Intellectual Humility

We were able to address the first research question by analyzing the results of the Intellectual Humility survey (see Appendix B) given at the beginning of the semester (“pre-survey”) and at the end of the semester (“post-survey”) to students in both courses. Three methods of viewing the data gave insight into the personality constructs of current introductory physics students.

First, we determined the Intellectual Humility perspectives of the students at the beginning of the semester, irrespective of whether they were in the traditional or the interactive course, by finding the mean response values of all of the participants for each of the three survey dimensions: love of learning, appropriate discomfort with limitations, and owning intellectual limitations. Figure 4.1 displays a bar chart combined with a whisker plot to present the descriptive statistics of the pre-survey results for all of the students. The numerical averages are given by the corresponding numbers on the bars themselves, and the error bars are the standard deviations of responses. Responses were reverse-coded for negatively-worded items, so here 5 represents the most favorable response and 1 the least favorable response. For the dimension of love of learning, the mean response was 4.46 ($SD = 0.758$), the minimum response was 2, and
the maximum response was 5. For the dimension of appropriate discomfort with limitations, the mean response was 2.86 ($SD = 1.199$), the minimum response was 1, and the maximum response was 5. For the dimension of owning intellectual limitations, the mean response was 3.68 ($SD = 0.975$), the minimum response was 1, and the maximum response was 5.

![Pre-Survey Mean Responses for Both Courses Combined](image)

*Figure 4.1. Bar chart of mean pre-survey responses of all student participants by dimension of Intellectual Humility.*

The findings show that students in both the traditional and interactive course had a high level of love of learning; however, there was a moderate-low average for the dimensions of appropriate discomfort with limitations and owning intellectual limitations. These aggregate results paint the picture of how introductory level physics students think about components of Intellectual Humility in the classroom, regardless of which type of classroom they proceed to engage in.

A more detailed approach to the pre-survey responses enabled us to compare the two types of course by breaking down the pre-survey responses not only by dimension, but also by
type of learning environment. The students in the traditional classroom had pre-survey mean responses of 4.43 ($SD = 0.763$), 3.00 ($SD = 1.152$), and 3.73 ($SD = 0.943$) for the Intellectual Humility dimensions of love of learning, appropriate discomfort with limitations, and owning intellectual limitations, respectively. The students in the interactive classroom had pre-survey mean responses of 4.61 ($SD = 0.731$), 2.49 ($SD = 1.303$), and 3.52 ($SD = 1.027$), respectively. Figure 4.2 illustrates this comparison of means in a bar chart combined with a whisker plot. Again, the numerical averages are given by the corresponding numbers on the bars themselves, and the error bars are the standard deviations of responses.

![Figure 4.2. Bar chart of mean pre-survey responses of students in both courses by dimension of Intellectual Humility and course.](image)

At the beginning of the semester, students in the traditional course held more favorable epistemological beliefs than students in the interactive course with respect to the dimensions of appropriate discomfort with limitations and owning intellectual limitations. Students in the
interactive course held more favorable perspectives as related to Intellectual Humility with respect to the dimension of love of learning. Table 4.1 displays the descriptive statistics and independent samples t-test values of the pre-survey responses of both courses for each dimension of Intellectual Humility. At the $\alpha = 0.05$ significance level for an independent samples t-test, the means of the two courses were only significantly different for the dimension of appropriate discomfort with limitations. That is, the students in the two courses were comparable to the extent of the two dimensions of love of learning and owning intellectual limitations.

*Table 4.1. Descriptive statistics and independent samples t-test p-values for the pre-survey.*

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Course (total responses)</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>$p$ - value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Love of Learning</td>
<td>Traditional (N = 120)</td>
<td>4.43</td>
<td>0.763</td>
<td>0.137</td>
</tr>
<tr>
<td></td>
<td>Interactive (N = 56)</td>
<td>4.61</td>
<td>0.731</td>
<td></td>
</tr>
<tr>
<td>Appropriate Discomfort with</td>
<td>Traditional (N = 120)</td>
<td>3.00</td>
<td>1.152</td>
<td>0.010*</td>
</tr>
<tr>
<td>Limitations</td>
<td>Interactive (N = 55)</td>
<td>2.49</td>
<td>1.303</td>
<td></td>
</tr>
<tr>
<td>Owning Intellectual Limitations</td>
<td>Traditional (N = 120)</td>
<td>3.73</td>
<td>0.943</td>
<td>0.189</td>
</tr>
<tr>
<td></td>
<td>Interactive (N = 56)</td>
<td>3.52</td>
<td>1.027</td>
<td></td>
</tr>
</tbody>
</table>

* = Significant at the 0.05 level

The third way we looked at the survey responses was separately comparing the pre-survey and post-survey responses for each course. In this way, we gained insight into how engaging in the two different learning environments may have changed the way students perceived and responded to statements about Intellectual Humility between the beginning and the end of the semester. Figure 4.3 illustrates the comparison of pre- and post-survey mean responses within the traditional course broken down by dimension of Intellectual Humility.
survey, in the form of a bar chart combined with a whisker plot. The numerical averages are given by the corresponding numbers on the bars themselves, and the error bars are the standard deviations of responses. The students in the traditional classroom had post-survey mean responses of 4.33 ($SD = 0.774$), 2.92 ($SD = 1.179$), and 3.73 ($SD = 0.972$) for the Intellectual Humility dimensions of love of learning, appropriate discomfort with limitations, and owning intellectual limitations, respectively.

![Traditional Course Pre vs. Post Survey Results](image)

*Figure 4.3. Bar chart of mean pre- and post-survey responses of students in the traditional course.*

Figure 4.4 illustrates the comparisons of pre-survey and post-survey mean responses within the interactive course broken down by dimension of Intellectual Humility survey, in the form of a bar chart combined with a whisker plot. The numerical averages are given by the corresponding numbers on the bars themselves, and the error bars are the standard deviations of responses. The students in the interactive classroom had post-survey mean responses of 4.61 ($SD = 0.567$), 2.57 ($SD = 1.345$), and 3.82 ($SD = 1.020$) for the Intellectual Humility dimensions
of love of learning, appropriate discomfort with limitations, and owning intellectual limitations, respectively.

![Interactive Course Pre vs. Post Survey Results](image)

**Figure 4.4.** Bar chart of mean pre- and post-survey responses of students in the interactive course.

In the traditional class, the mean response to survey questions in the dimensions of love of learning and appropriate discomfort with limitations decreased, while the mean response to survey questions in the dimension of owning intellectual limitations remained the same. In the interactive class, the mean response to survey questions in the dimensions of appropriate discomfort with limitations and owning intellectual limitations increased, while the mean response to survey questions in the dimension of love of learning remained the same. Table 4.2 gives the descriptive statistics and independent samples t-test p-values for the pre-survey vs. post-survey means by dimension of Intellectual Humility for each course. Neither course experienced a statistically significant difference in mean response for any of the three dimensions between the two survey administrations, so neither type of learning environment
significantly altered students’ self-reported personality constructs related to Intellectual Humility over the course of the semester.

Table 4.2. Descriptive statistics and independent samples t-test p-values for the pre- vs. post-survey responses.

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Course</th>
<th>Pre-survey Mean, SD (N)</th>
<th>Post-survey Mean, SD (N)</th>
<th>p - value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Love of Learning</td>
<td>Traditional</td>
<td>4.43, SD = 0.763 (N = 120)</td>
<td>4.33, SD = 0.774 (N = 60)</td>
<td>0.451</td>
</tr>
<tr>
<td></td>
<td>Interactive</td>
<td>4.61, SD = 0.731 (N = 56)</td>
<td>4.61, SD = 0.567 (N = 28)</td>
<td>1.000</td>
</tr>
<tr>
<td>Appropriate Discomfort with Limitations</td>
<td>Traditional</td>
<td>3.00, SD = 1.152 (N = 120)</td>
<td>2.92, SD = 1.179 (N = 59)</td>
<td>0.647</td>
</tr>
<tr>
<td></td>
<td>Interactive</td>
<td>2.49, SD = 1.303 (N = 55)</td>
<td>2.57, SD = 1.345 (N = 28)</td>
<td>0.669</td>
</tr>
<tr>
<td>Owning Intellectual Limitations</td>
<td>Traditional</td>
<td>3.73, SD = 0.943 (N = 120)</td>
<td>3.73, SD = 0.972 (N = 60)</td>
<td>0.956</td>
</tr>
<tr>
<td></td>
<td>Interactive</td>
<td>3.52, SD = 1.027 (N = 56)</td>
<td>3.82, SD = 1.020 (N = 28)</td>
<td>0.204</td>
</tr>
</tbody>
</table>

These comparisons only begin to shed light on the role of Intellectual Humility in a more interactive, problem solving heavy physics classroom versus a traditional, lecture based physics class, as we discuss in the next chapter. Our analysis provides significant evidence regarding students’ self-reports about their Intellectual Humility under a limitations-owning perspective, compared for students enrolled in a traditional course format and those in an interactive course format. Analysis of the written reflections and in-class observations deepen our findings from the surveys as well.
Discussion and Reflections on Learning Experiences

We were able to address the second research question by analyzing the student written reflections, in which the students described and talked about their in-class tendencies, perspectives of learning, and values within the classroom. Inductive and deductive coding of the written reflections for all students yielded 27 codes. Each code was narrowly defined to avoid overlap between codes and to ensure they clearly represented the complexity of the data. Appendix D provides the codebook with definitions and an example of a written reflection to which each code was applied. Once these well-defined codes were applied to all reflections, a second layer of analysis revealed that codes could be grouped together into three overarching categories: Mindset, In-class Behavior, and Course Component. Each of these categories and their corresponding codes are presented in Table 4.3 below and they are described and further explained through their corresponding codes in the rest of this subsection. These findings will be supported and illustrated using excerpts from the students’ reflections.

Table 4.3. Categories and corresponding codes from analysis of qualitative data.

<table>
<thead>
<tr>
<th>Category</th>
<th>Codes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mindset</td>
<td>Clarification of Concepts</td>
</tr>
<tr>
<td></td>
<td>Correct Mistake</td>
</tr>
<tr>
<td></td>
<td>Open Mindset</td>
</tr>
<tr>
<td></td>
<td>Change in Confidence</td>
</tr>
<tr>
<td></td>
<td>Identify Gaps</td>
</tr>
<tr>
<td></td>
<td>Emotions</td>
</tr>
<tr>
<td></td>
<td>Superiority</td>
</tr>
<tr>
<td></td>
<td>Reconsider Understanding</td>
</tr>
<tr>
<td></td>
<td>Correct Answer</td>
</tr>
<tr>
<td></td>
<td>Admitting Limitations</td>
</tr>
<tr>
<td>In-class Behavior</td>
<td>Groupwork</td>
</tr>
<tr>
<td></td>
<td>Collaboration</td>
</tr>
<tr>
<td></td>
<td>Question</td>
</tr>
<tr>
<td>Learning Community</td>
<td>Mindset. This category refers to student responses that reflected <em>intrapersonal</em> beliefs, preferences, and emotions as related to their learning experiences in a physics classroom. This category encompasses ten codes as described below.</td>
</tr>
<tr>
<td>Peer Attitudes</td>
<td>The code <em>Clarification of Concepts</em> indicated that the student described their need to rethink and clarify physics knowledge for personal understanding of the material. One student wrote the following excerpt, which exemplifies this code: “Lab manual helps clarify concepts learned in lecture, as well as teach students how to properly apply said concepts when analyzing experimental data.” <em>Correct Mistake</em> meant that the student identified a desire to correct a mistake or misunderstanding during problem solving. One student described, “The homework set up makes it extremely difficult to learn because it usually does not help you whatsoever when you get a question wrong.” <em>Open Mindset</em> indicated that the student described how a willingness to listen to and consider the thoughts of others affects their learning. As one student discussed in relation to preferred attitudes of their peers during groupwork, “Openness to dialogue and questions makes me more likely to engage.” <em>Change in Confidence</em> reflected that the student described a gain or loss of confidence in academic conversations when his or her approach or</td>
</tr>
<tr>
<td>Engagement</td>
<td></td>
</tr>
<tr>
<td>Professor Interaction</td>
<td></td>
</tr>
<tr>
<td>Primary Participant</td>
<td></td>
</tr>
<tr>
<td>Secondary Participant</td>
<td></td>
</tr>
<tr>
<td>Analyze Evidence</td>
<td></td>
</tr>
<tr>
<td>Argumentation</td>
<td></td>
</tr>
<tr>
<td>Seek External Help</td>
<td></td>
</tr>
<tr>
<td>Pretending</td>
<td></td>
</tr>
<tr>
<td>Course Component</td>
<td></td>
</tr>
<tr>
<td>Audible Distractions</td>
<td></td>
</tr>
<tr>
<td>Focused Content</td>
<td></td>
</tr>
<tr>
<td>Graded Work</td>
<td></td>
</tr>
<tr>
<td>Classroom Resources</td>
<td></td>
</tr>
</tbody>
</table>
response is proven wrong. One student described that they “feel a loss of confidence and try to think about why [they were] wrong and why the correct approach is correct.” Identify Gaps was defined as when the student described an effort to identify any limits in their conceptual knowledge as part of the learning process. Upon recognition of a mistake, one student said they “just want to know where [they] went wrong and how to fix it.” Emotions reflected that the student described feelings such as anxiety, stress, or insecurity after his or her method/knowledge is challenged/proven wrong. Reflecting in response to when his or her approach is proven wrong, one student wrote that they “feel a bit stupid, but feeling stupid makes [them] learn.” Superiority meant that the student described the impact of claiming superiority over others during an academic conversation in the physics classroom. One student discussed peer behaviors that either help or hinder their engagement in academic conversation in the following excerpt: “If they are rude or try to make themselves superior, I kind of stop listening. But if they are willing to help me understand, I will learn from them better.” Reconsider Understanding referred to when the student described that they revisit their approach/thoughts about a problem, upon their approach being challenged or proven wrong in academic conversation. One student simply discussed that they “reconsider [their] understanding” when their approach to a problem is incorrect. Correct Answer referred to when the student identified that getting the correct answer is a priority of academic discussions. One student described that the focus of groupwork is getting to the correct response: “Whatever the right answer, we should be agreeing on that.” Admitting Limitations was defined as when the student recognized the benefits/drawbacks of admitting to themselves and/or others that they have a gap in their knowledge of the physics content. One student wrote that if they do not know enough to engage in the group discussion, they “let others know and try to follow their explanation.”
**In-class Behaviors.** This category refers to when a student described his or her behavioral tendencies and styles of *interpersonal* actions with peers, as related to their learning experiences in the physics classroom. This category encompasses thirteen codes as described below.

*Groupwork* referred to when the student described their preferences related to working with peers on an assignment in the classroom during labs, problem solving sessions, etc. as related to their learning experiences. One student negatively described working in groups with unmotivated peers: “I hate working with people who contribute nothing, I have to carry their weight and I learn nothing from them.” *Collaboration* was defined as when the student described outcomes of discussing, analyzing, explaining, and troubleshooting with others. One student wrote about how certain class activities foster collaboration with peers: “The tutorials make me more prone to engage because I can work out the problems with others.” The code *Question* indicated that the student described how either he/she or his/her peers asking questions to other students in the class impacts their understanding of physics concepts. One student discussed the utility of questions being asked in the classroom: “I like it when my peers ask questions that result from trying to build their physical intuition.” *Learning Community* referred to when the student discussed the role of social relationships and familiarity in classroom learning and interactions. The following excerpt from one reflection highlights this facet: “My group has been in the same classes for 3 semesters now so we work together really well and know what helps each other learn.” *Peer Attitudes* reflected that the student discussed how the interest level/attitudes that their peers hold toward the physics content impacts classroom interactions/learning experiences. As one student reflected, “Peers who demonstrate passive and unmotivated attitudes toward presented physics concepts greatly discourage my participation in
an academic conversation.” Engagement signified that the student described an increase or decrease in engaging in discussions, explanations, and providing of feedback/critique in an academic conversation about a topic they are not confident in. One student wrote about the positive effects of working with motivated peers with respect to engagement in groupwork: “Having optimistic and engaged attitudes greatly increases the productivity of a group by encouraging members to question and reflect on presented physics concepts.” Professor Interaction was defined as when the student described the role of the professor during in-class activities. One student discussed a preference toward less professor interaction: “I think teachers should take a hands-off approach when managing groupwork – be available, but don’t interrupt.” Primary Participant indicated that the student described the effects of initiating or actively engaging in an academic discussion about a topic they are not confident in. When uncomfortable with material, a student discussed that “it doesn’t affect [their] engagement, [they] will always try to engage so [they] can understand material.” Secondary Participant referred to when the student described their willingness to engage and participate in groupwork if a conversation is initiated by someone else in a discussion about a topic they are not confident in. One student reflected that they contribute to academic conversations more often if they are not the starter of the discussion: “If someone else initiates the conversation, I am more likely to engage.” Analyze Evidence indicated that the student described the role of investigating their steps in solving a problem. One student described this as a problem solving strategy: “We will each explain our strategy and sometimes will try both to see which seems more right. Sometimes one of our approaches falls apart part way through trying it.” Argumentation meant that the student discussed the role of collaborative argumentation – explaining each other’s opinions and methods and then critiquing and choosing the best one – in classroom discussions. Upon
disagreement with peers, one student wrote that they “will argue [their] point and also hear [their peers’] side and work to a compromise.” Seek External Help signified that the student described a means of learning or filling a knowledge gap by reaching out to external sources. Without proper knowledge to solve problems in class, one student wrote that they “will either look things up or ask a TA in order to make sure [they] know how to do the problem.” Pretending indicated that the student discussed a tendency to pretend that they know the course content in academic conversation. One student described that they will “pretend to know for a while till a TA comes by” if they are unsure of the correct approach.

**Course Components.** This category refers to when a student described how elements of the physics course itself and facets of the physical classroom contribute to their learning experiences. This category encompasses four codes as described below.

*Audible Distractions* meant that the student described audible noises in the classroom setting that impact their learning. In the large lecture setting of the traditional class, one student described that “no one respects the professor, they talk when he’s talking and leave early which distracts him and derails the class.” *Focused Content* signified that the student described the importance of keeping all elements of the course in line with the same learning objectives or conceptual content. The following excerpt illustrates a preference toward focused content: “I like labs that are directly related to course content – that is, no complicated derivations that need to be understood beforehand.” *Graded Work* meant that the student described the impact of graded work on conceptual understanding and learning experiences. One student described that graded work hinders conceptual understanding: “Board activities are the best for me when we don’t have to turn in the work. I find my group and I are more concerned with understanding the
process to complete the problem vs. when we have to turn something in, we care less for learning and more for tangible results to turn in.” Classroom Resources was applied when the student identified a particular physical resource in the classroom that either enhances or hinders their learning experience. One student wrote that computers offer a collaborative resource for peers during lab: “Computers (tablets, laptops, etc.) allow group members to share generated data and simultaneously contribute to the writing of an experimental report while providing feedback and critique to each other.”

**Embodiment of Intellectual Humility**

We were able to address the third research question primarily through the performance and analysis of in-class observations. The researcher recorded field notes throughout observation sessions, and then the same codes and categories from the written reflections were applied to the field notes. In this way, we linked and compared what students said in their reflections to what they actually did in the classroom, both verbally and behaviorally. The findings of this analysis are presented by categories and corresponding codes. These are supported using excerpts from the researcher’s notes as indicated.

**Mindset.** Clarification of Concepts was evident in the interactive course when “the TA briefly discussed the lab experiments. He asked if the students knew about the resonance frequency of the RLC circuits or if he should briefly explain it. One student said ‘Please briefly explain it’” (Field Notes Observation #2, Interactive Course). Here, the student verbally indicated a need to clarify physics knowledge to improve their understanding, in particular the concept of resonance frequency. Correct Mistakes was not applied to any of the observation field notes, as no students discussed nor enacted this code’s definition. Open Mindset was not
directly observed, but this makes sense because it is thought-based, rather than verbally or physically visible. *Change in Confidence* was only interpreted to occur physically in one instance in the interactive course, during which a student solved a problem on the whiteboard and used the wrong units of mass: “The student who was presenting made a sigh-type sound signifying he understands where he went wrong” (Field Notes Observation #1, Interactive Course). The verbal sigh indicated to the observer a loss in confidence within the student upon their approach being proven wrong or mistaken. *Identify Gaps* was not applied to any field notes, presumably because this may remain a completely internal process. *Admitting Limitations* took place in both classrooms, and mostly in the form of students saying the phrase “I don’t know.” In the interactive course, “a student recognized that his final answer was off by a factor of 1000. He said ‘I messed up somewhere somehow, but I don’t know’” (Field Notes Observation #1, Interactive Course). In the traditional course, “one student was clicking through their collected graphs and said ‘Yeah this is the best one, but I’m not even sure if it’s right’” (Field Notes Observation #1, Traditional Course). In both situations, the students’ dialogues portray a verbal admittance of a limitation in their ability to complete the lab. *Emotions*, *Superiority*, *Correct Answer*, and *Reconsider Understanding* were not observed; these are all aspects of student mindsets and so may be intrapersonal by nature.

**In-class Behaviors.** *Groupwork* was present insofar as students physically completed tasks with peers: “In one group [of the traditional course], one member released the weight from the origin, while a second member collected data on the computer system. The third member observed, with his chair moved over to the side with the computer” (Field Notes Observation #1, Traditional Course). *Collaboration* played a noticeably more present role in the interactive classroom as opposed to the traditional classroom. During an RC Circuits lab, the researcher
noted that “there is more talking and conversation than in the traditional lab. It is easy for group members to point to the computer and show the other people what they are talking about” (Field Notes Observation #2, Interactive Course). Similar to Groupwork, Collaboration is more clearly embodied by behaviors of discussing, analyzing, and explaining than students describing how these actions pertain to their learning. However, a comparison of how groups in each type of classroom collaborate provides strong evidence about how an interactive learning environment fosters and facilitates these conversations among peers. In the interactive class, whiteboards, seat orientation, and computers were purposely set up to allow students to “discuss and work out answers” (Field Notes Observation #2, Interactive Course) together; the traditional lab required students to “reposition their chairs to get closer to the experimental setup” (Field Notes Observation #1, Traditional Course). These differences will be detailed more when we discuss in-class resources. Question was embodied in two different ways: one student asking a question to another student, or a student asking a question to the TA. In the traditional course, this occurred when one student “asked the TA a question about the two masses in the setup. After working for awhile by themselves, the same student asked her group mate, ‘Are we assuming that the pulley is frictionless?’” (Field Notes Observation #1, Traditional Course). Here, we see both scenarios come into play – the same student asks both the TA and his or her peer questions related to the lab to enhance his or her understanding. Field notes also captured Question in the interactive course in a similar way through interactions with the TA or among classmates. The previous field note also exemplifies Seek External Help in that the student recognizes a limitation in his or her knowledge, and reaches out to the TA for help, which was observed in both classroom formats. Learning Community was much more present in the interactive course than the traditional course. In the traditional course, “some groups were more friendly and joking
toward one another, while others were very quiet and not interactive” (Field Notes Observation #1, Traditional Course). In the interactive course, though, “the lab groups were self-made and so it seemed that people tended to stick with people similar to them – a group of all females, of all white males, and of all students of Chinese ethnicity. Students were likely to be comfortable with their group mates (as told to me by the instructor)” (Field Notes Observation #1, Interactive Course). This is an interesting comparison in that in both courses, the role of familiarity and social relationships impacted the level at which students conversed and interacted. In the interactive course, self-assembled groups enhanced students’ comfort working with one another and resulted in students working with others of similar identity. Peer Attitudes was only slightly present in that one student in the interactive class verbally conveyed, “I hate electricity. I have no interest in this” (Field Notes Observation #2, Interactive Course). Engagement was not directly observed as no students verbally communicated how different academic situations altered their level of engagement in discussions. Professor Interaction was applied mostly to the interactive course. In general, the course instructors played a more reserved role during lab assignments: “TAs and instructors were in no hurry to give out answers to student questions. They asked them to talk it out to them and tried to get them to think through and basically answer their own questions” (Field Notes Observation #1, Interactive Course). This is in line with the in-class behaviors of the instructors, as they served to answer small questions and guide students through the lab without too much contact. In the traditional course, however, the TA still served as an important relayer of information and readily answered student questions about lab procedures. Primary Participant was observed in the interactive class when one female student said to her group, “I think it’s fine if you hook it up like that. I don’t know though because I’m not an expert” (Field Notes Observation #2, Interactive Course). Despite the topic
of conversation being something the student did not seem to be overly knowledgeable about or confident in, the student still actively engaged in the discussion. *Secondary Participant* was difficult to both observe and code in the field notes in that there may be many reasons that a student is hesitant or unwilling to be fully engaged in a lab or academic conversation. As such, we were not able to determine whether a lack of engagement or participation was due to a lack of internal confidence about a topic. *Analyze Evidence* was evident in verbal conversations in which students investigated parts of their problem solving efforts. In the interactive class, two students looked back at their approach to the lab: “One group member asked ‘Where is this $10^4$ coming from?’ and the other replied ‘Because this is in Volts’” (Field Notes Observation #2, Interactive Course). So, in the classroom the act of looking back at the steps one takes to solve a problem also leads to conceptual understanding, in this particular case the student who was asking gained clarity about the units of electricity concepts. *Argumentation* was a clear component of the interactive class. Two different situations exemplify this. In one situation, “some of the groups compared their oscilloscopes to other groups sitting near them. One student said ‘That looks better than ours.’ Another student said ‘Yours makes sense’” (Field Notes Observation #2, Interactive Course). In a similar instance during the same lab session, “the groups compared their numerical answers, and tried to resolve any discrepancies by looking at the equations they used” (Field Notes Observation #2, Interactive Course). In both cases, students engaged in collaborative argumentation at the group level in that they explained each other’s results and approaches and provided feedback and critique to one another. *Pretending* was not observed, and this is likely due to the inability of an observer to decipher whether a student is focused on the work or is just pretending to know a concept.
**Course Components.** The observations of *Classroom Resources* are an important point of comparison between the two classes because this is a direct result of the two separate teaching styles. In the traditional course, the lab groups sat around a rectangular table at which there was one computer and one experimental setup. Due to this, “many students made use of standing up and moving their physical location either toward the lab setup, lab computer, or another student’s laptop to understand the lab or collect data” (Field Notes Observation #1, Traditional Course). Whereas the traditional classroom required a lot of movement and rearrangement for students to successfully engage with one another, the interactive classroom setup facilitated conversations and collaboration: “The classroom layout was 4 triangular tables and 5 projectors/whiteboards along the perimeter. Groups of two or three were able to see the computer and experimental setup all at the same time from where they are seated” (Field Notes Observation #2, Interactive Course). These two field notes about the physical setup of the classrooms and how students interact around these resources provides a contrast in teaching styles. In the interactive course, tables and computers were appropriately placed such that all group members were naturally facing the experiment and computer, which facilitated conversations and working with peers on one shared set of equipment. On the other hand, the rectangular tables and singular computer for each group in the traditional course made it more difficult for students to engage with equipment and collaborate on the computer — they had to physically get up and move around to see and participate in the lab. Even at the end of the traditional lab sessions, “the data analysis was done by individuals separately on their own laptops” (Field Notes Observation #1, Traditional Course). Thus, the code *Classroom Resources* is important in identifying how the physical classroom settings of traditional versus interactive courses impact student interactions. The
codes *Audible Distractions, Focused Content*, and *Graded Work* were not exemplified in our observations.

As a whole, each of the codes that we were able to apply to the observations gave valuable insights into how some of the written reflections are actually embodied in the classroom through verbal communications and physical behaviors. We compare these two sources of data in the following chapter.
Chapter 5: Discussion

In this chapter, we discuss our findings from the previous chapter by connecting to both the theoretical framework and to the existing literature. In addition, we interpret the survey responses, written reflections, and in-class behaviors relative to the perspective of Intellectual Humility as well as synthesize the data sources to convey new insights given by this study.

Self-Reported Intellectual Humility

Our preliminary analysis of the survey data unveiled an overall picture of how introductory physics students perceived the three dimensions of Intellectual Humility in the classroom. The students as a whole had a substantial love of learning; however, as presented in the findings and seen in Table 4.2, there is potential for improvement in the dimensions of appropriate discomfort with limitations and owning intellectual limitations for introductory physics students. It is important to note that what we saw in the preliminary, big picture analysis became clearer with our secondary analysis. What seemed to have caused the value to be low in the overall mean of appropriate discomfort with limitations were the responses from the students in the interactive course. There was a large standard deviation in the overall average response, and the interactive course had a statistically significant lower mean score for this dimension. It is interesting to note that the students in the interactive course had already had one full semester of engaging in an interactive learning environment before taking this course. Perhaps this implies that at this stage students need additional support to understand how to appropriately manage discomfort with limitations, through means such as a purposeful Intellectual Humility intervention.
The results of the final mode of analysis that we performed on the survey data were probably the least intuitive. We compared the student survey responses in each respective course between the beginning and the end of the semester (the two survey administrations). It was interesting that neither course underwent a statistically significant difference in any dimension of Intellectual Humility. This indicates that students’ personality constructs, from a limitations-owning perspective, were firm to the extent that the students agreed with the survey statements in similar ways before and after engaging in their respective learning environments. These statistical test results revealed that in itself, without any purposeful Intellectual Humility intervention, an interactive class setting for introductory physics courses may not necessarily significantly foster or cultivate traits aligned with Intellectual Humility, given that the students in the interactive course did not have significant changes in how they self-identified with each of the dimensions of Intellectual Humility. Such a result is illuminating in that Intellectual Humility itself is directly related in collaboration with peers and engaged discussions; however, the learning environment centered on academic conversations in this study did not seem sufficient to significantly change student perceptions about the three dimensions of Intellectual Humility. This again points to the potential need for more explicit conversations or reflections with students about how Intellectual Humility affects collaborative work.

Even though the statistical tests did not render significant differences, the results of the students’ self-reported Intellectual Humility were positive in the active learning environment. For the dimension of love of learning, the interactive course’s mean response remained the same while the mean response of the traditional course decreased. In addition, both the pre- and post-survey mean responses for the interactive class for this dimension were higher than those of the traditional course. It thus seems that a collaboration-based physics learning environment may
foster a larger love of learning than the traditional, large lecture style format. It is worth repeating that the interactive course was comprised of students majoring or intending to major in physics, while the traditional course’s students were mostly engineering majors. This may have impacted the students’ interest in and motivation toward learning the field of physics; however, we believe the disciplines of physics and engineering are related enough that this factor may not limit our interpretations. For the dimension of appropriate discomfort with limitations, the interactive course’s mean response increased between the pre- and post-survey, whereas the traditional course’s mean response decreased. It again seems that the interactive learning format may play a role in promoting the dimensions of Intellectual Humility measured in the survey, in comparison to the traditional setting. The numerical values of the mean responses for this dimension, however, were overall (pre- and post-survey) higher and thus more favorable for the traditional course than the interactive course for both survey administrations. Although the pre-to post-survey change increased for the interactive course, it did appear that the students in the traditional course held more favorable epistemic worldviews from the limitations-owning perspective of Intellectual Humility. One plausible reason that may explain these findings is that students may have been largely uncomfortable working with peers and engaging in academic discussions with others, especially as often as was required of them in the interactive course. Students in the traditional course may have felt more comfortable about their limitations because in this format they were not compelled to admit them to their peers. The fact that the interactive students constantly engaged with one another and were put into situations in which their limitations were exposed and still had an increase in their mean survey response to this dimension points to the important effects of active learning settings. For the dimension of owning intellectual limitations, the interactive course’s mean response increased over the
semester, while the traditional course’s mean response remained the same. Additionally, the numerical value of the interactive course’s mean response for this dimension was higher than that of the traditional course for the post-survey. Similar to the dimension of love of learning, it seems that the active learning environment fosters students’ personality constructs that align with the limitations-owning view of Intellectual Humility. Students who engaged in a more collaborative learning environment ultimately held more favorable epistemic beliefs toward learning and toward their personal limitations, which emphasizes the role of cooperative work in fostering the virtue of Intellectual Humility.

Largely, the results from students’ self-reported Intellectual Humility stipulate both that introductory physics students in general have room to improve their epistemological worldview via a purposeful Intellectual Humility intervention and that an interactive learning environment may cultivate more favorable epistemological beliefs in students than a traditional setting.

**Discussion and Reflections on Learning Experiences**

Our findings from the student written reflections have been discussed in so far as we have applied a coding scheme to unify them. To sufficiently address the second research question, we must ground these codes and categories in the theoretical framework of Intellectual Humility such that we can see our findings from the perspective of our underlying theoretical lens.

**Mindset.** The students’ reflections related to the code *Clarification of Concepts* reinforced the following statement on the Intellectual Humility survey, which falls under the dimension of love of learning: “If I don’t understand something, I try to get clear about what exactly is confusing to me” (Haggard et al., 2018) in that the students were able to communicate
their tendency to clarify physics knowledge for their personal understanding. In the written reflections, we saw that students were holding favorable beliefs toward the virtue of Intellectual Humility in this respect. Student responses coded as *Correct Mistake* were also important in understanding how introductory students think about Intellectual Humility. The reflections indicated that students desired to correct mistakes and misunderstandings when solving problems, which is in support of the following survey statement: “When I don’t understand something, I try hard to figure it out” (Haggard et al., 2018). Moreover, the students’ reflections agreed with the predictor that “IH increases a person’s concern about her own intellectual mistakes and weaknesses” (Whitcomb et al., 2017). Both the survey statement and the predictor were represented in the student discussions of their learning experiences, since they described a personal objective to resolve mistakes and knowledge gaps. Our choice of the code name *Open Mindset* was purposive in that Intellectual Humility is similar to, but distinct from, the concept of Open-mindedness. One of the predictors from our theoretical framework proposes that “IH increases a person’s propensity to consider alternative ideas, to listen to the views of others, and to spend more time trying to understand someone with whom he disagrees” (Whitcomb et al., 2017). To us, this is captured in the name of the code, as students must be open to listening to their peers and considering counterarguments to their own convictions. Intellectual Humility is thus the recognition that one holds false beliefs and maintains fallibility as an owner of knowledge, while Open-mindedness slightly differs in its definition as one’s recognition that their beliefs are subject to change (Spiegel, 2012). *Change in Confidence* is related to a few theoretical underpinnings of Intellectual Humility. Whitcomb et al. (2017) project the predictor that “IH increases a person’s propensity to hold a belief with the confidence that her evidence merits.” The students’ reflections illustrated this idea in that many students described a loss of
confidence when they knew their convictions were erroneous. This code also related to the survey statement, “When I know that I have an intellectual weakness in one area, I tend to doubt my intellectual abilities in other areas as well,” which is under the dimension of appropriate discomfort with limitations (Haggard et al., 2018). If comfort coincides with confidence, and discomfort with a lack of confidence, then it seems that students were both uncomfortable and less confident when their approach to a problem was wrong. Since student reflections pertaining to how their confidence changes in response to uncertainty about a content area are not favored by the worldview of Intellectual Humility, we again believe that a purposive intervention could yield benefits to student mindsets. The code Identify Gaps is perhaps one of the most Intellectual Humility-driven concepts found within the reflections. From the limitations-owning perspective, it is essential that an intellectually humble individual be able to point to his or her limits or gaps in knowledge. Such a concept is illustrated not only in the students’ written descriptions of their mindsets, but also in their responses to the survey questions related to the dimension of owning intellectual limitations, specifically: “I am quick to acknowledge my intellectual limitations” (Haggard et al., 2018). Both courses had a moderately favorable mean response to this dimension in the pre- and post-surveys, and the correspondingly coded reflections reinforced these results. Further, Whitcomb et al. (2017) write the predictor: “IH increases a person’s propensity to have a clearer picture of what he knows and justifiedly believes and what he neither knows nor justifiedly believes.” This is to say that students must have an appropriate gauge on which physics concepts they understand and which parts of a problem or concept they do not have appropriate evidence to understand. This was evident in their reflections, as many students discussed that pinpointing where their knowledge or understanding was flawed or missing is important in the learning process. Emotions and the corresponding reflections served
as a point of contrast between student descriptions and the prediction that “IH reduces feelings of anxiety and insecurity about one’s own intellectual limitations” (Whitcomb et al., 2017). In the reflections, students described feeling anxious and stressed when their method or opinion was proven wrong in a discussion, and this is in conflict with favorable epistemic beliefs toward academic conversations associated with Intellectual Humility. Although the students’ perceptions of emotions were at odds with what Intellectual Humility deems favorable, it is important that the students described the role of emotion in the classroom to begin with. Church and Samuelson (2016) discuss that emotional intelligence and the relation between emotions and reason in the pursuit of knowledge is an important trait of a virtuous individual. It seems that there is room for improvement with respect to how students react emotionally to academic situations, as students seem prone to negative emotions when they are mistaken in the classroom. 

Superiority was also in line with a predictor from the theoretical framework: “IH reduces a person’s propensity to treat intellectual inferiors with disrespect on the basis of his (supposed) intellectual superiority” (Whitcomb et al., 2017). In the reflections, we saw this in the form of attitudes towards peer behaviors, as students described that they were unlikely to engage with peers who made themselves superior to them in conversations. Reflections coded Reconsider Understanding related to the prediction that “IH increases a person’s propensity to revise a cherished belief or reduce confidence in it, when she learns of defeaters” (Whitcomb et al., 2017). As students discussed that they revisited and revised their convictions upon hearing other evidence from their peers, it is evident that student mindsets align with the virtue of Intellectual Humility in this respect. Correct Answer is rooted in the worldview of Intellectual Humility only from the perspective that an epistemically virtuous individual seeks out and desires to know the truth. In the dimension of love of learning, the survey statement “I care about truth” aligned with
the students’ written descriptions of their prioritization of getting the right answer to a problem rather than understanding why it is the right answer (Haggard et al., 2018). Intellectual Humility embraces the pursuit of correct answers, but correct is not the absolute aim as is the pursuit of an answer: Intellectual Humility is concerned with the virtuous method(s) of getting to a correct solution. Admitting Limitations is a foundational component of Intellectual Humility and the student reflections represented well the favorable action of telling others about one’s personal limitations. The first predictor from Whitcomb et al. (2017) is that “IH increases a person’s propensity to admit his intellectual limitations to himself and others.” Similarly, the survey dimension of owning intellectual limitations addresses students’ tendencies toward and comfort with admitting their limitations. Students described in their reflection responses that they would let other people in their group know when they did not understand a concept so that they could get the help they needed, and this is in line with the limitations-owning definition of Intellectual Humility.

**In-class Behaviors.** As we have just seen, all of the codes within the Mindset category are strongly related to Intellectual Humility in the way it is defined and addressed in general in the literature. The category of In-class Behaviors, however, is where the findings of this study extend the scholarship by offering new insights into this epistemological virtue as applied to an educational setting.

The three codes Groupwork, Engagement, and Collaboration stress interpersonal actions in the classroom, such as discussing and explaining concepts with classmates and solving problems with peers. This undoubtedly turns one’s intellectual focus on his or her peers and calls upon one’s ability to successfully engage in dialogue with others. Such an ability to both
recognize and enact upon the importance of working with peers, which was evident in the
reflections, aligns with the predictor that “IH tends to decrease focus on oneself and to increase
focus on others” (Whitcomb et al., 2017). Students described their preferences of explaining
concepts and troubleshooting during labs with their group mates, which encompasses the
favorable others-focused component of Intellectual Humility. Question and Seek External Help
are related codes in that they both exemplify how students look for other sources of knowledge
to fill a personal intellectual limitation. This is indicative of the following predictor: “IH
increases a person’s propensity to defer to others who don’t have her intellectual limitations, in
situations that call upon those limitations” (Whitcomb et al., 2017). In the two cases, students
preferred to personally ask conceptual questions to clarify course content or work with peers who
were not afraid to ask questions (Question) and the students tended to use external resources
when they did not know how to solve a problem (Seek External Help). Thus, the student
reflections aligned with the qualities of the theoretical view of Intellectual Humility used in the
study. Reflections coded as Pretending exemplified an unfavorable behavior through the lens of
Intellectual Humility, as “IH reduces both a person’s propensity to pretend to know something
when he doesn’t and his confidently answering a question whether or not he knows the answer”
(Whitcomb et al., 2017). Some students described that if they did not know the topic of
discussion, they would pretend to know the concept during the proceeding academic
conversation. This directly goes against the Intellectual Humility predictor that an intellectually
humble student will be less likely to act as if they know something when they actually do not, as
this would allow the student to actually understand what they are trying to learn and may also
benefit the entire group’s understanding of the issue at hand. From the perspective of this code,
then, introductory students may acquire more favorable behavioral tendencies if provided with
an Intellectual Humility intervention that discourages behaviors of pretending to know material. \textit{Analyze Evidence} is an important component of Intellectual Humility, particularly in its application to education, in that students should be cautious of their methods and pay attention to their problem solving approaches. Many students described this tendency in themselves or within their group to investigate their solution steps, and this is closely related to what we coded as \textit{Argumentation}. This code is slightly different in that students did not only describe critiquing and revising their own approaches, but also working with others to find the best strategies and revising their personal method upon agreement at the group level. Both of these codes illustrated the predictor that “IH increases a person’s propensity to revise a cherished belief or reduce confidence in it, when she learns of defeaters (i.e. reasons to think her belief is false or reasons to be suspicious of her grounds for it)” (Whitcomb et al., 2017). The two codes, \textit{Analyze Evidence} and \textit{Argumentation}, indicated student reflections about reconceiving their own approaches and really going through their methods to find and accept defeaters, which aligns with our philosophical lens.

\textit{Learning Community} was a unique finding in that there is literature that relates to it, such as communities of practice in education (Lave, 1991); however, we were unable to find any published works that investigate or hint at the connections between such communities and the virtue of Intellectual Humility. This finding was telling of the nature of the interactive course in that the reflections described groups of students that were familiar with one another and comfortable working together due to prolonged engagement. A “community of practice” is a joint enterprise of members that are mutually engaged over time, sharing communal resources, in pursuit of a common goal (Wenger, 1998). It is interesting not only that the students in the interactive course reflected positively on this facet of their groupwork, but also that the
interactive course’s mean survey responses for the dimensions of appropriate discomfort with limitations and owning intellectual limitations increased over the course of the semester. To contrast, the students in the traditional course did not know their group mates before this semester and did not write about feeling comfortable or familiar with their peers. Their mean survey responses for the same two dimensions of Intellectual Humility decreased and remained the same, respectively. Of course we cannot assume any causal relationship, but it is plausible that familiarity with peers does provide comfort in owning one’s intellectual limitations in the classroom.

Likewise, *Peer Attitudes* conveyed a different facet of Intellectual Humility in that students discussed preferences for their group mates, such as interest in the material. Turning back to the work of Tanesini (2016), Intellectual Humility can be viewed as a grouping of attitudes related to self-acceptance and modesty and that can be seen in four dimensions: concern for one’s own limitations; concern for those of others; concerns for one’s own successes; concern for others’ successes. This projects again an others-focused element to Intellectual Humility, which was portrayed in the reflections when students described concerns about their peers and how their peers’ attitudes and motivations impacted groupwork.

*Professor Interaction* is not related as much to Intellectual Humility as it is to comparing the two types of learning environments under investigation in this study. Nonetheless it was brought up unprompted in students’ reflections. Students in both courses described that instructors should be available for questions, offer help during labs, and manage groupwork only when needed. The professor played a lot more active of a role in the traditional course in that he or she was the primary relayer of information, example problems, and knowledge during lecture,
whereas by nature, the interactive course places less stress on the presentation of information and rather the emphasis is on group problem solving (Sokoloff et al. 2011). The reflections, however, did not suggest a strong difference in student preferences between the two learning formats with respect to the professor interaction; yet as mentioned, students tended to discuss this in their reflections about the classroom environment. As many students brought up the role of the instructor in a classroom in response to what traits of either a lab section or of individuals in the classroom impact their engagement, it seems that the professor plays an important role in cultivating a learning environment that favors Intellectual Humility.

*Primary Participant* and *Secondary Participant* were also revealing codes that are related to Intellectual Humility, but have not been directly related to the theory in the past. Especially in the context of students in science classrooms working together to solve a problem, these concepts uncovered a lot about both the mindsets and behaviors of students. *Primary Participant*, in the sense that students initiated conversations and actively engaged even about a topic they were not knowledgeable about, may serve as a contrast to what Intellectual Humility predicts. The theory suggests that an intellectually humble student should reduce confidence in his or her beliefs upon recognition that it is incorrect. However, it seemed that most students who identified as primary participants proceeded in academic conversations not to project their flawed knowledge, but in pursuit of understanding the truth. This is in line with Intellectual Humility, so long as the student does not actively put forward mistaken convictions. In a similar manner, *Secondary Participant* meant that students would take a more reserved role in conversations about a topic about which they were not confident. This aligns with the prediction that an intellectually humble individual is more likely reduce confidence in a belief for which there are defeaters, but taking a secondary role needs to be considered with caution as too much
of it would go against the prediction that an intellectually humble individual should defer to others and reach out to external sources in active pursuit of knowledge. The interplay of these two types of conversationalists, as well as which one is more favorable in terms of Intellectual Humility, is an interesting topic and one that future work could certainly explore.

**Course Components.** *Audible Distractions*, which was applied to reflections describing noises in the classroom that impact learning experiences, yielded more insight into the classroom settings than into Intellectual Humility. Students in the traditional, large lecture course discussed that other students talking to one another in the stadium-style classroom largely distracted them from learning. That is, the physical setup of the traditional classroom was susceptible to side conversations and a lack of focus on the instructor’s presentation, whereas the smaller enrollment of the active engagement class did not yield any reflections describing such distractions. These findings are important as they lead us to believe that the interactive format would be a better setup to foster Intellectual Humility than the traditional classroom settings. Similarly, at the outset *Focused Content* did not appear to link directly to Intellectual Humility as it pertains to the classroom. This code reflected that students preferred labs and course activities that did not stray far from the course concepts. In a way, this finding suggests that students perceive that they are better able to gain a deep conceptual understanding under these activities and would therefore be better positioned and prone to engage in intellectually humble academic conversations than less focused activities. *Graded Work*, which captured instances in the reflections about how the students expressed that they were more likely to understand the material if a given assignment was not submitted for a grade, presents a more implicit tie with Intellectual Humility. Trussell and Dietz (2003) found that electrical engineering students whose homework was graded performed worse on a conceptual assessment than those whose homework was not graded;
however, in another semester of the same experiment, the assessment scores of the two groups of students were not significantly different. This study suggests that perhaps leaving homework, and possibly other in-class assignments, ungraded will not reduce the conceptual knowledge gains of the students, and may therefore reduce tension to allow for an atmosphere where students can more easily engage in generative discourse and open the opportunity for them to develop Intellectual Humility. Classroom Resources offered an informative difference between the two academic settings as well. As previously mentioned, the physical layout of the interactive course – triangular tables angled toward computers and projectors/white boards around the entire classroom – facilitated group conversation and access to lab equipment. Student reflections from the interactive course indicated that the white boards and table set-up eased peer interactions; the students in the traditional course focused more on the lab equipment itself in their reflections, since their lecture setting was not conducive of a more preferable active learning environment. Although past studies have shown that active and cooperative learning environments are beneficial for physics students’ knowledge acquisition and motivation to learn (Ho & Boo, 2007), the reflections from this study offer a qualitative view of these effects and allow students’ opinions to be voiced. As mentioned in the literature review, the physical setup of a classroom may encourage more active learning behaviors from the students, which in turn facilitates opportunities to engage in discussions with peers and analyze data with group mates. Although not previously investigated, perhaps a classroom layout in and of itself has the potential to impact how often students converse and how favorable students act in such discourse, with respect to Intellectual Humility.
Embodiment of Intellectual Humility

As mentioned and reported in the findings related to in-class observations, the same codes and categories were applied to the researchers’ field notes. The findings and codes for the students’ embodiment of Intellectual Humility connect to the same theoretical concepts and literature as just discussed. In this section, we will synthesize the observation results with the written reflections, such that we can couple these two data sources to paint an aggregate picture of the mindsets and behaviors of introductory physics students. It is important to note that our results from these observations of student behaviors and interactions comprise an original contribution to the literature and thus it is not possible to draw comparisons to previous studies as we did in the previous sections. However, we will discuss how the survey findings of the recent study by Krumrei-Mancuso et al. (2019) are supplemented and reinforced by some of our qualitative in-class observations findings.

Mindsets. **Clarification of Concepts** was embodied in the classroom via a student asking the teaching assistant to explain a particular concept that was not entirely clear initially. This is in line with the written reflections in that many students described that they strive for personal understanding of the material, mostly through rethinking and clarifying physics concepts. **Change in Confidence** occurred behaviorally when a student sighed upon recognition of his or her mistaken approach. The reflections with this code similarly indicated a slight loss of confidence in academic conversations in which their response was incorrect, so the in-class behavior aligned with the written reflections. **Admitting Limitations** took place in both classrooms, when students verbally indicated to their group mates that they were unsure of their approach or that they knew their methods were mistaken. This also emerged in written
reflections in which students described that they admitted to others that they had a gap in their understanding of specific physics content. Embodiment of Intellectual Humility in the sense represented by this code also aligns with the finding from Krumrei-Mancuso et al. (2019) that more intellectually humble individuals have a higher self-awareness about their personal knowledge.

**In-class Behaviors.** *Groupwork* as the defined code arose in our findings only as an observed behavior; that is, when students worked with peers to complete certain tasks such as problem solving and acquiring results during lab. There were no instances in which students discussed out loud, while they were in the classroom, their preferences about groupwork and how groupwork relates to their learning experiences, so the results of the observations served to understand what the students referred to when they mentioned groupwork in the reflections and also to properly analyze such data. *Collaboration* was embodied by behaviors of discussing, analyzing, and explaining, and this took different forms in each classroom format. In the written reflections, students often indicated that both labs and in-class assignments encouraged collaboration with peers and that such collaboration often resulted in recognition of knowledge gaps as well as learning by listening to others. Krumrei-Mancuso et al. (2019) likewise found that higher Intellectual Humility is associated with a tendency to participate in cognitive tasks and less social vigilanism. *Question* was observed in both classroom formats when students asked one another or the instructor questions related to the course material. This is in line with the corresponding written reflections for this code, as students mostly stated a preference toward asking questions about physics concepts to help them learn. *Learning Community* was more apparent in the interactive class in that they were all very familiar with one another and with the learning strategies of their peers. Many students reflected that working with the same people for
a prolonged period of time improved their social relationship with peers and helps them learn, so this code is behaviorally characterized in the same way as students wrote about in their reflections. *Peer Attitudes* was observed when a student expressed verbal disinterest in the lab topic to his peers. The reflections indicated that students preferred when their peers showed interest and a positive attitude toward the subject, whereas in observations we found examples of students manifesting complete disinterest. In the interactive course, *Professor Interaction* involved a minimized role of the instructor and a higher emphasis on working with peers. The reduced interactions between students and professors seemed to be preferable in the written reflections as well, as exemplified in the previous section. *Primary Participant* was observed in the interactive class even in cases in which the initiator may not have had a full understanding of the topic at hand. This is in line with some of the written reflections, in which some students indicated that they still initiated conversations and engaged even though they may not have been confident about the topic. *Analyze Evidence* was noticeable in verbal conversations in which students investigated parts of their problem solving efforts and looked back at their methodical steps. These actions agree with the reflections where students discussed the importance of conversing with peers about strategies and approaches to be able to reach a conclusive answer. *Argumentation* was distinctly exhibited when students explained each other’s results and approaches and provided feedback and critique to one another. This process was also evident in the reflections, as students described their tendency to hear others’ methods and opinions and come to a compromise upon any academic disagreements.

**Course Components.** *Classroom Resources* as observed in each class offered an insightful contrast between the two learning environments. Students in the interactive course were able to easily see the shared computer and lab set up, as well as use the nearby whiteboards
to solve problems together. Many reflections from students in this classroom format similarly
discussed that the classroom setup facilitated conversation and groupwork. In contrast, the
traditional course’s lab classroom necessitated the physical relocation of students to see the data
on the computer or work tangibly with the lab equipment. These students discussed in their
reflections that the computers allowed for collaboration; however, classroom observation
findings revealed that in this classroom format there was no common place during lecture for
students to work together on solving problems. That is, the in-class observations again
reinforced the findings from the reflections of the students, and provided actual visual and
behavioral evidence to what the students voiced in their writings.
Chapter 6: Concluding Remarks and Future Directions

In this chapter, we offer a concluding summary of our study; in addition, we offer suggestions for future research directions that attend to the limitations mentioned in the Methodology chapter as well as other possible investigations that extend the work of the study presented here.

Concluding Remarks

In this mixed methods study, we collected self-reported Intellectual Humility survey responses, written reflections to two questionnaires, and in-class observations from both a traditional and interactive electricity and magnetism course in order to explore perceptions, mindsets, and behaviors of introductory physics students through the philosophical lens of Intellectual Humility. Our study adds to the emerging body of knowledge in education that focuses on three defining dimensions of Intellectual Humility under the limitations-owning approach: love of learning, appropriate discomfort with limitations, and owning intellectual limitations.

Our study revealed that in both classroom settings students’ perceptions of love of learning were at the moderate-high level both at the beginning and at the end of their courses experiences, with a higher mean value for participants in the interactive setting at the end of semester. Students perceptions with respect to owning intellectual limitations were not as high, but the results show a moderate self-reported level for this dimension, again with a higher mean for the group in the interactive setting. On the other hand, in the dimension of appropriate discomfort with limitations we found that students perceive themselves at the moderate-low level
in both classrooms settings both at the beginning and at the end of their course experiences. Interestingly, the results for this dimension show that the students in the interactive setting had a lower mean than those in the traditional setting. From our analyses of students written reflections and observations, we surmise that these results are actually compatible with the nature of the interactive setting, where students are more exposed to confronting their limitations, and thus become more aware of their discomfort with it. Moreover, the evidence gathered from the thematic analyses of written reflections and observations, and the comparisons of these findings, indicate that students in the interactive format expressed and espoused more indicators of Intellectual Humility than their peers in the traditional format. Taken together, our findings suggest that the interactive setting is more conducive to developing Intellectual Humility than the traditional format.

In addition, our study stresses the importance of the need for providing additional support to students so that they can learn how to manage discomfort with limitations in an appropriate way. Thus, while this study provides a first step in understanding the connections between new advances in physics learning and Intellectual Humility, further work is necessary to solidify and extend our findings in order to better understand these connections and enhance the learning of physics and the development of Intellectual Humility in physics classrooms.

**Future Directions**

Future studies should attend to the limitations of this study that were described in Chapter 3. Specifically, more studies are needed that involve the same or similar data collection methods with a larger quantitative sample size, such that survey responses and the corresponding statistical tests would have stronger statistical power. These studies would help validate our
findings or help adjust them in a way that can be generalizable to the entire population of introductory physics students.

We also mentioned earlier the lack of knowledge about both the student participants and the instructors of the courses. Future studies should incorporate interviews or administer surveys to the students that draw more background information and personal beliefs from them. In this way, student written reflections and survey responses could be grounded in or at least be closely related to their experiences outside of the physics classroom. Moreover, interviews with the professors and teaching assistants would yield a needed perspective towards the classroom and give an interesting standpoint of how students perceive and embody the dimensions of Intellectual Humility in the classroom and how this can be used to improve physics education.

In addition, the research presented here has raised the need for further research that includes the design and implementation of an intervention component that directly addresses Intellectual Humility in the physics classroom, which would allow for the investigation of the implications of teaching students to embody this epistemic virtue in academic settings. An intervention may take many different forms, but some suggestions are to directly teach the concept of Intellectual Humility to the students and discuss examples of academic conversations that exemplify different Intellectual Humility dimensions; alternatively, interventions can be designed to address specific deficiencies such as appropriate discomfort with limitations.

We also propose that further research can apply our data collection and analysis methods to other physics courses and other scientific disciplines. This may include upper division physics courses such as quantum mechanics, as well as longitudinal studies that trace students’ long-term embodiment of Intellectual Humility in the classroom over multiple years of physics coursework.
As we argued in the literature review, contemporary learning theories call for a necessary shift in education in all scientific disciplines. The prospect of being able to determine the implications that Intellectual Humility may have in the learning of mathematics, biology, chemistry, engineering, and other related courses would provide stimulus for further research to illuminate contrasts between the disciplines or unifying patterns among them that will benefit all students.
References


Appendix A: Intellectual Humility Predictors


1. IH increases a person’s propensity to admit his intellectual limitations to himself and others.
2. IH reduces both a person’s propensity to pretend to know something when he doesn’t and his confidently answering a question whether or not he knows the answer (think: “male answer syndrome”).
3. IH reduces a person’s propensity to blame and explain-away when confronting her own intellectual shortcomings.
4. IH decreases a person’s propensity to set unattainable intellectual goals.
5. IH increases a person’s propensity to defer to others who don’t have her intellectual limitations, in situations that call upon those limitations.
6. IH increases a person’s concern about her own intellectual mistakes and weaknesses.
7. IH reduces feelings of anxiety and insecurity about one’s own intellectual limitations.
8. IH decreases a person’s propensity to excessively compare herself to others intellectually.
9. IH reduces the intellectual aspect of the self-serving bias in a person, which is, very roughly, the propensity to attribute to oneself more responsibility for intellectual success than for intellectual failures.
10. IH increases a person’s propensity to revise a cherished belief or reduce confidence in it, when she learns of defeaters (i.e. reasons to think her belief is false or reasons to be suspicious of her grounds for it).
11. IH increases a person’s propensity to consider alternative ideas, to listen to the views of others, and to spend more time trying to understand someone with whom he disagrees.

12. IH increases a person’s propensity to seek help from other sources about intellectual matters.

13. IH increases a person’s propensity to hold a belief with the confidence that her evidence merits.

14. IH increases a person’s propensity to have a clearer picture of what he knows and justifiedly believes and what he neither knows nor justifiedly believes.

15. IH reduces a person’s propensity to expect or seek recognition and praise for her intellectual strengths and accomplishments.

16. IH reduces a person’s propensity to treat intellectual inferiors with disrespect on the basis of his (supposed) intellectual superiority.

17. IH tends to decrease focus on oneself and to increase focus on others.

18. IH increases a person’s propensity to accurately estimate her intellectual strengths.

19. IH decreases a person’s propensity to be obsessed with his strengths and to boast about them.
Appendix B: Intellectual Humility Survey

Items from Limitations-Owning Intellectual Humility Scale (p. 192, 2018) as developed by Haggard, M., Rowatt, W. C., Leman, J. C., Meagher, B., Moore, C., Fergus, T., ... & Howard-Snyder, D. in Finding middle ground between intellectual arrogance and intellectual servility: Development and assessment of the limitations-owning intellectual humility scale. Personality and Individual Differences, Volume 124.

I. Love of Learning

1. If I don't understand something, I try to get clear about what exactly is confusing to me.
2. When I don't understand something, I try hard to figure it out.
3. I love learning.
4. I care about truth.

II. Appropriate Discomfort with Limitations

1. I focus on my intellectual weaknesses too much.*
2. When I know that I have an intellectual weakness in one area, I tend to doubt my intellectual abilities in other areas as well.*
3. When I think about the limitations of what I know, I feel uncomfortable.*
4. I tend to get defensive about my intellectual limitations and weaknesses.*

III. Owning Intellectual Limitations

1. I have a hard time admitting when one of my beliefs is mistaken.*
2. When someone points out a mistake in my thinking, I am quick to admit that I was wrong.
3. I am quick to acknowledge my intellectual limitations
4. I feel comfortable admitting my intellectual limitations.

*Indicates reverse coded items
Appendix C: Reflection Questionnaires

Reflection 1 Questions:
1. What resources in the classroom enable or hinder you in learning physics concepts?
2. Are there any resources in the classroom that you would attribute to making you more (or less) prone to engage in academic discussions with your group members? If so, which ones and how?
3. What attitudes and behaviors of your peers enable or hinder you in learning physics concepts?
4. What attitudes and behaviors of your peers make you more (or less) prone to engage in an academic conversation with them?
5. Which labs/types of labs are most helpful in learning the physics content? Why?
6. Which labs/in-class activities help you engage most successfully with your peers? Why?

Reflection 2 Questions:
1. When you are solving problems in a group during class time, do you try to identify and correct any gaps in your knowledge? Why? (for the grade, to understand, …) and how? (ask others, online search, TA, … please elaborate.)
2. What do you do if you feel that you do not know enough to engage in academic conversations with your peers during class time?
3. If you or other people in your group disagree with an approach/strategy/solution, do you take any steps to resolve it? If so, describe. If not, how do you choose how to proceed?
4. How do you feel when your approach/response in the groupwork is challenged or proven wrong?
5. When you are proven wrong while working in groups, how does that affect your engagement in further discussions?
6. With the previous 5 questions in mind, what attitudes and behaviors of your peers enable or hinder you in learning physics concepts?

7. Are there other comments in line with the previous 6 questions that you would like to add?
Appendix D: Codebook

<table>
<thead>
<tr>
<th>Code</th>
<th>Definition</th>
<th>Example Reflection</th>
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<tbody>
<tr>
<td>Clarification Of Concepts</td>
<td>The student describes their need to rethink and clarify physics knowledge for personal understanding of the material.</td>
<td>“Lab manual helps clarify concepts learned in lecture, as well as teach students how to properly apply said concepts when analyzing experimental data.”</td>
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<tr>
<td>Correct Mistake</td>
<td>The student identifies a desire to correct a mistake in problem-solving or correct a misunderstanding.</td>
<td>“The homework set up makes it extremely difficult to learn because it usually does not help you whatsoever when you get a question wrong.”</td>
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<tr>
<td>Groupwork</td>
<td>The student describes their preferences related to working with peers on an assignment in the classroom during labs, problem-solving sessions, etc. as related to their learning experiences.</td>
<td>“I hate working with people who contribute nothing, I have to carry their weight and I learn nothing from them.”</td>
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<tr>
<td>Collaboration</td>
<td>The student describes outcomes of discussing, analyzing, explaining, and troubleshooting with others.</td>
<td>“The tutorials make me more prone to engage because I can work out the problems with others.”</td>
</tr>
<tr>
<td>Audible Distractions</td>
<td>The student describes audible noises in the classroom setting that impact their learning.</td>
<td>“No one respects the professor, they talk when he's talking and leave early which distracts him and derails the class.”</td>
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<tr>
<td>Question</td>
<td>The student describes how either he/she or his/her peers asking questions to other students in the class impacts their understanding of physics concepts.</td>
<td>“I like it when my peers ask questions that result from trying to build their physical intuition, but not if professors don’t work to understand where they're coming from.”</td>
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<td>Learning Community</td>
<td>The student discusses the role of social relationships and familiarity in classroom learning/interactions.</td>
<td>“My group has been in the same classes for 3 semesters now so we work together really well and know what helps each other learn.”</td>
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<td><strong>Peer Attitudes</strong></td>
<td>The student discusses how the interest level/attitudes that their peers hold toward the physics content impacts classroom interactions/learning experiences.</td>
<td>“Peers who demonstrate passive and unmotivated attitudes toward presented physics concepts greatly discourage my participation in an academic conversation.”</td>
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<td><strong>Engagement</strong></td>
<td>The student describes an increase or decrease in engaging in discussions, explanations, and providing of feedback/critique in an academic conversation about a topic they are not confident in.</td>
<td>“Having optimistic and engaged attitudes greatly increases the productivity of a group by encouraging members to question and reflect on presented physics concepts.”</td>
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<tr>
<td><strong>Professor Interaction</strong></td>
<td>The student describes the role of the professor during in-class activities.</td>
<td>“I think teachers should take a hands-off approach when managing groupwork - be available, but don’t interrupt.”</td>
</tr>
<tr>
<td><strong>Open Mindset</strong></td>
<td>The student describes how a willingness to listen to and consider the thoughts of others affects their learning.</td>
<td>“Openness to dialogue and questions makes me more likely to engage.”</td>
</tr>
<tr>
<td><strong>Primary Participant</strong></td>
<td>The student describes the effects of initiating or actively engaging in an academic discussion about a topic they are not confident in.</td>
<td>“It doesn't affect my engagement, I will always try to engage so I can understand material.”</td>
</tr>
<tr>
<td><strong>Secondary Participant</strong></td>
<td>The student describes their willingness to engage and participate in groupwork if a conversation is initiated by someone else in a discussion about a topic they are not confident in.</td>
<td>“If someone else initiates the conversation, I am more likely to engage.”</td>
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<tr>
<td><strong>Focused Content</strong></td>
<td>The student describes the importance of keeping all elements of the course in line with the same learning objectives or conceptual content.</td>
<td>“I like labs that are directly related to course content - that is, no complicated derivations that need to be understood beforehand.”</td>
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<tr>
<td><strong>Graded Work</strong></td>
<td>The student describes the impact of graded work on conceptual understanding and learning experiences.</td>
<td>“Board activities are the best for me when we don’t have to turn in the work. I find my group and I are more concerned with understanding the process to complete the problem vs. when we have to turn something in, we care less for learning and more for tangible results to turn in.”</td>
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<tr>
<td><strong>Change In Confidence</strong></td>
<td>The student describes a gain or loss of confidence in academic conversations when his or her approach/response is proven wrong.</td>
<td>“I feel a loss of confidence and try to think about why I was wrong and why the correct approach is correct.”</td>
</tr>
<tr>
<td><strong>Analyze Evidence</strong></td>
<td>The student describes the role of investigating their steps in solving a problem.</td>
<td>“We will each explain our strategy and sometimes will try both to see which seems more right. Sometimes one of our approaches falls apart part way through trying it.”</td>
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<tr>
<td><strong>Identify Gaps</strong></td>
<td>The student describes an effort to identify any limits in their conceptual knowledge as part of the learning process.</td>
<td>“I just want to know where I went wrong and how to fix it.”</td>
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<tr>
<td><strong>Argumentation</strong></td>
<td>The student discusses the role of collaborative argumentation – explaining each other's opinions and methods and then critiquing and choosing the best one – in classroom discussions.</td>
<td>“I will argue my point and also hear their side and work to a compromise.”</td>
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<tr>
<td><strong>Correct Answer</strong></td>
<td>The student identifies that getting the correct answer is a priority of academic discussions.</td>
<td>“Whatever the right answer, we should be agreeing on that.”</td>
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<tr>
<td><strong>Seek External Help</strong></td>
<td>The student describes a means of learning or filling a knowledge gap by reaching out to external sources.</td>
<td>“I will either look things up or ask a TA in order to make sure I know how to do the problem.”</td>
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<tr>
<td><strong>Admitting Limitations</strong></td>
<td>The student recognizes the benefits/drawbacks of admitting to themselves and/or others that they have a gap in their knowledge of the physics content.</td>
<td>“I wish my peers could recognize being confused is a good thing.”</td>
</tr>
<tr>
<td><strong>Classroom Resources</strong></td>
<td>The student identifies a particular physical resource in the classroom that either enhances or hinders their learning experience.</td>
<td>“Computers (tablets, laptops, etc.) allow group members to share generated data and simultaneously contribute to the writing of an experimental report while providing feedback and critique to each other.”</td>
</tr>
<tr>
<td><strong>Pretending</strong></td>
<td>The student discusses a tendency to pretend that they know the course content in academic conversation.</td>
<td>“I pretend to know for a while till a TA comes by.”</td>
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<tr>
<td><strong>Emotions</strong></td>
<td>The student describes feelings such as anxiety, stress, or insecurity after his or her method/knowledge is challenged/proven wrong.</td>
<td>“I feel a bit stupid but feeling stupid makes me learn.”</td>
</tr>
<tr>
<td><strong>Superiority</strong></td>
<td>The student describes the impact of claiming superiority over others during an academic conversation in the physics classroom.</td>
<td>“If they are rude or try to make themselves superior, I kind of stop listening. But if they are willing to help me understand I will learn from them better.”</td>
</tr>
<tr>
<td><strong>Reconsider Understanding</strong></td>
<td>The student describes that they revisit their approach/thoughts about a problem, upon their approach being challenged or proven wrong in academic conversation.</td>
<td>“I reconsider my understanding.”</td>
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