# EXAMINING PHYSICS IDENTITY IN LABORATORY SETTINGS THROUGH SURVEY DEVELOPMENT

By

Kelsey Marie Funkhouser

A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

Astrophysics and Astronomy – Doctor of Philosophy

2019

**ABSTRACT**

EXAMINING PHYSICS IDENTITY IN LABORATORY SETTINGS THROUGH SURVEY DEVELOPMENT

By

Kelsey Marie Funkhouser

Labs have been closely tied with physics education for well over a century. In that time practitioners have struggled to take advantage of the unique opportunities provided by lab learning environments. Recently, there have been renewed calls to emphasize the practices and skills of 'doing physics' in lab courses. Physics education has struggled to utilize labs to their full potential and to assess the impacts labs have on the students. This dissertation will describe the design and implementation of an algebra-based sequence of lab courses at Michigan State University (MSU). In the course design, lab skills and practices are the central learning goals instead of content specific knowledge. We utilize the context of the newly redesigned lab courses to develop an assessment tool to measure the impact that labs are having on our students, specifically on their physics identity development. An essential aspect of developing a physics identity is the opportunity to engage in the practices that are authentic to the field of physics. From a robust understanding of students' ideas about these practices, we can get information about how they situate themselves with respect to the practices as an indicator of their physics identity. We assert that the survey development process we have undergone to produce a practice-based identity survey, has ensured that the survey accurately represents how students interpret these practices and how they identify with them. We have taken a mixed methods approach to reduce the items and overall dimensions of the survey into a fully closed-responses short form survey of 24 practice and 5 identity focused questions. This dissertation describes the process of developing the practice-based identity survey from the context and theoretical model through each iteration of the survey.

This thesis is dedicated to Scott Funkhouser and The Duchess of Fluffington.
I could not have done this without the both of you.

# ACKNOWLEDGEMENTS

I want to start by thanking the Department of Physics and Astronomy for allowing me to be the first Astrophysics graduate student to complete a thesis in physics education research here at MSU. I also want to thank my committee for supporting me in this process.

I want to thank my advisors, Vashti Sawtelle and Danny Caballero, for first accepting an astrophysicist into their physics education research group and then nurturing me into the researcher I am today. To Kim Crosslan who has always had my back and is the best physics mom there is. We are so lucky to have you.

I want to thank the astronomy and PER graduate students who have been beside me through my time here. I will always remember and value the support, solidarity, distractions, and everything else your friendships have provided. I want to thank PERL@MSU, the many iterations of the group in my time here. It has been a place where I could grow as a researcher and a physicist and I will be forever grateful for that.

I want to thank everyone who has been involved in the DATA Labs over the years, from faculty to TAs and LAs to students. Working with all of you has been a gift. Although it was not always smooth sailing, every bit was worth it.

I want to thank a few teachers without whom I would not be here. First, my 9th grade physical science teacher Mr. Fields, who boosted my love of science at just the right time. To my high school AP Physics teacher, Dr. Kim Moore, thanks for pushing me to jump into AP. Finally, my college astronomy teacher, Dr. Chris Laws, who shared with us the wonders of the universe.

I want to thank my family for their love and support. I especially want to thank my parents, who have no college experience to speak of but have produced three college educated daughters. Thank you for instilling in me a passion for learning, for trusting me in my pursuits, and for your continued pride in my accomplishments. I love you both very much. Finally, I want to thank my husband, *Dr.* Scott Funkhouser. I am so grateful that you are in my life and that we have grown in directions that complement and support each other. I am excited for our next adventure. I love you.

**TABLE OF CONTENTS**

## LIST OF TABLES

## LIST OF FIGURES

# CHAPTER 1

# INTRODUCTION

Lab experiences have been a central aspect of physics and science education for well over a century as evidenced by a quote from Griffin in 1892, "the laboratory has won its place in school; its introduction has proved successful. [...] Pupils will go out from our laboratories able to see and do" (Griffin 1892, cited by [6, 7]). Lab activities represent the hands-on and practical process of 'doing science.' Since their establishment as essential to science education there has been a struggle to appropriately and effectively assess the impacts they are having on our students' learning and development [8, 9, 7, 10, 11]. Most recently there have been national calls to focus on practices, from the National Research Council in the Next Generation Science Standards and in the American Association of Physics Teachers (AAPT) Committee on Laboratories and their recommendations for undergraduate physics labs [12, 5]. Both push for reforms in science education that emphasis the practices and skills fundamental to the process of doing science. As it is understood, practices are the ways of knowing, doing, and participating in a specific community. Today, as historically true, the goals of labs in education are to provide students with opportunities to engage in the authentic practices necessary in doing physics (or science more generally). Lab courses are uniquely structured to produce these opportunities and as such it is important that the design of these courses reflect that structure by emphasizing practices in design and assessments[1] in the course. As we are meant to be preparing the next generation of physicists we need to use the opportunities we have to train them in what it means to be a part of the physics community. This connection makes the motivation for instructing physics majors this way but they are not the only populations that we teach and not the only populations who will benefit from experience with physics practices. The skills and practices valued in physics are relevant for all STEM fields, just as the subject of physics itself is. Labs are spaces for this authentic engagement in practices but,

[1] Measurement tools developed to assess specific areas of interest (content knowledge, beliefs, etc.). Often in the form of multiple choice tests or surveys.

these authentic experiences also positively impact students' attitudes and beliefs about physics, as well as other affective measures [13, 14, 15, 16, 17]. Engagement with the practices of a particular community are fundamental to forming a community-specific identity [4]. Identity is a multidimensional construct that describes how someone perceives and positions themselves with respect to a specific community. The strength of one's identity has been found to correlate with persistence and belonging [18, 19, 20]. It has also been posited that identity development (or struggles with it) can be linked to underrepresentation of white women and people of color in some STEM programs [20, 19]. Seeing as physics labs are in need of large scale assessments, engagement with practices influences identity, and identity can be linked to persistence, belonging, and underrepresentation in physics, it is not such a stretch to focus work on this. Motivation also comes from the experience of working in the transformed course described in Chapter 3. The emphasis on practices and other adjustments to the course resulted in completely different attitudes and levels of engagement from the students (see Sec. 3.6 for some evidence of this).

With the motivation for this specific focus laid out it is also important to include justification for the development of a survey as opposed to a fully qualitative investigation. The first reason has already been discussed: the community of physics lab education is in need of large scale and broadly applicable assessments of the impacts of these courses. There is not quantitative work being done on identity in physics labs, and the identity specific qualitative work has been focused on upper division students and physics majors. The lab transformation described in Ch 3, which has been the main data source for the survey development, is an introductory algebra-based physics lab for non-physics majors. The mode, context, and focus of this work are unique and therefore relevant to both the study of physics identity and physics labs.

This dissertation presents the development of a survey to measure the connection between physics labs experiences and the physics identity of students. In Chapter 2, we provide an overview of the history of labs in science and physics education in order to illustrate the goals related to practices. We also discuss the lack of large scale assessments for evaluating the impacts of these courses. We propose that a survey to measure physics identity in lab classes is a valuable addition to the field. The different perspectives on identity in the literature are summarized, and our focus on communities of practice is justified.

Chapter 3 describes a large-scale course transformation we conducted here at Michigan State University in the introductory lab courses for non-physics majors. This chapter establishes the context where the majority of the data discussed in the dissertation were obtained. The new course was designed to center lab practices as called for in the AAPT Lab guidelines [5]. This chapter outlines which practices the transformation centers on and how that translates to the classroom. It also includes the only large-N assessment available to evaluate the lab transformation, the E-CLASS [1].

In Chapter 4, we focus on the identity-specific work done in the process of developing the survey. The main focus is on working to operationalize[2] a model[3] of identity used in Close et al. (2016) [21] into laboratory contexts, including the context described in Chapter 3. This involved the development of a codebook[4] from interviews with students in lab classes and an open-response survey. After successfully operationalizing identity in this context, we evaluated the data's fit to the Close et al. model of identity from the literature. The model in question was a combination of two different frameworks on identity [4, 19]. Through the analysis of both data sources we found that the individual components of the identity model could be applied to our context, but we saw no evidence of the components being combined.

Chapter 5 is a bridge from the end of the identity analysis of Chapter 4 to the survey specific work in Chapter 6. This chapter provides additional insight into the development of Version 1 of the survey and the open-response questions. It is also a snapshot of our perspective on identity at the beginning of piloting different versions of the survey.

Chapter 6 provides an overview of the entire survey development process from theoretical framework to the current version of the survey. There is a special focus on the development

[2]To turn a theoretical construct into concrete parts that can be observed and/or assessed.

[3]A detailed description (or theoretical framework) developed to represent an abstract behavior or concept.

[4]A document listing the catagories generated in close analysis of student data along with detailed definitions and explanations.

and then reduction of survey questions over three different distributions (from 108 to 24 items). The chapter describes the qualitative and quantitative analysis performed at the different stages of development in order to produce the current, fully closed-response 24 item version of the survey.

Finally in Chapter 7, we discuss the dissertation as a whole, any implications of the work, and proposed next steps for the survey. We also include some of our own perspectives on identity, lab classes, and practices.

This survey is limited in scope: it is designed in the specific context of undergraduate physics labs and it should not be assumed to apply elsewhere, e.g., other science labs or combined lecture and labs, without additional validation. Along the same lines, the perspectives on identity presented here can not be simply moved into a physics lecture course or an informal learning space and be expected to represent identity development in those environments. Even in the specific learning environment of physics labs, the survey has not been validated with non-STEM majors, although there is no reason it could not be. We have been able to reduce the survey to a fully closed-response, relatively short version but complex analytics have not been completed and must be before any broad claims can be made from responses. This version of the survey needs to be distributed to a large number of students and analytics need to be done in order to determine what claims can be made about the quantitative results. This additional work was not possible within the constraints of the dissertation.

# CHAPTER 2

# LITERATURE REVIEW

As motivation for this work, I present a look at the establishment and study of physics labs in the literature, both historic and modern. The review highlights that the goals of lab instruction have always reflected the skills and practices necessary in 'doing science.' It describes the struggle to effectively evaluate the impacts of labs from their conception in physics education to today. As described below, lab experiences and engagement with authentic practices have been shown to impact students on attitudinal and affective measures. These impacts were observed in small scale studies, while large scale, broadly applicable assessments have been lacking. This struggle of assessment motivated my work to study how the focus on practices in lab courses impact the development of physics identity. The perspectives of identity development are discussed below along with the model for identity that I have selected and as further justification for this work. The conception of studying lab classes as communities of practice is introduced as justification for our model choice and this work on the impact lab experiences have on physics identity.

## 2.1 Physics Labs Historically

Prior to the Civil War, hands-on laboratories were not a part of the high school physics curriculum. The introduction of land grant colleges influenced the curriculum of high schools and in the 1870s, the lab method of teaching physical science, with a focus on the process of 'doing science', began popping up in high schools but was still rare until the 1890s [6]. The slow introduction was attributed to the cost of equipment and a lack of teachers with the necessary expertise. The Harvard List, a set of forty experiments of required experiments for admission in 1887, likely influenced the large jump in schools with laboratory physics from the 1880s to the early 1900s. In 1915 Edwin H. Hall described the influence of the Harvard List on high school physics, "it established the use of the laboratory as a most important element in the teaching of physics in secondary schools" (Edwin H. Hall, France in 1915 as cited by Rosen, 1953 [6]). The experiments indicated on the List were prescriptive and lead to a focus on measurement for measurement's sake, at least partially in opposition to the author Hall's own views [22]. In 1897 the List additionally reflected the suggestions of the Committee of Ten, a group of educators working to standardize the curriculum of American high schools. It was updated to emphasize a mixed course containing laboratories, lectures, and textbooks. Even with the updates and suggestions, labs took on the behavior of a fad becoming the dominant means of physics education, in some cases usurping lecture and textbooks entirely. By 1910, labs were a prominent part of physics education in the high schools even as Mann, whose perspective focused on the necessity of developing habits of mind, warned "we don't know how to use labs most effectively" [8]. While some questioned the benefit of labs in science education others, such as the founder of the progressive education movement, John Dewey, provided a perspective on what the goals of labs should be: "Science is more than a body of knowledge to be learned, there is a process or method to learn as well" [23].

After WWI labs were largely confirmatory and that was how things remained until the new science curricula of the 1960s, "which stress the process of science" [24]. In and around that time, educators were leaning on the unique opportunities provided by the labs for investigation and inquiry [25, 26, 27]. But even with the new push in science education in the 70s, the value of labs in science education were in question, in part because we lacked the tools to assess the specific benefits of labs. "Teachers who believe that the laboratory accomplishes something special for their students would do well to consider carefully what those outcomes might be, and then to find ways to measure them" [9]. Although the review by Bates highlighted evidence for labs improving skills in working with equipment, and positive attitudes. Bates also suggested that new assessments could and should be developed to measure the outcomes of labs because they "appear to represent a significantly different area of science learning than content acquisition."

This point was restated by Hofstein and Lunetta in their 1982 review of labs in science teaching [7]. They asserted that there had not been a comprehensive examination of the effects of lab instruction. They highlighted works listing the goals of laboratory work in science education. The goals of both inquiry and laboratory education at this time are reflective of what we now refer to as science practices. The goals include communicating [28], analyzing data [29], planning, and executing experiments [28, 24, 29], and understanding equipment [28, 30]. In addition to inquiry skills [31] and the scientific method [24].

## 2.2 Lab Practices and The New Standards of Science Education

Inquiry in science education came into focus again in the late 1990s with the National Science Education Standards (NSES) from the National Research Council and the goals for all students to achieve scientific literacy through inquiry [32, 33]. In the early 2000s came the development of the Investigative Science Learning Environment (ISLE), an introductory physics curricula with the goal of better preparing students for the modern workforce by helping them to develop abilities used in the doing of science [34, 35]. They define scientific abilities as “the most important procedures, processes, and methods that scientists use when constructing knowledge and when solving experimental problems” [35].

Recently there have been renewed pushes for an emphasis on practices in science and physics education. The Next Generation Science Standards (NGSS) name scientific and engineering practices as one of their central goals of science education, along with cross-cutting concepts, and core ideas [12]. In 2014 the American Association of Physics Teachers Committee on Laboratories came out with their Recommendations for Undergraduate Physics Laboratory Curriculum that centers the practices of science in six focus areas, modeling, designing experiments, developing technical and practical skills, analyzing and visualizing data, communicating physics, and constructing knowledge [5]. These national calls to better integrate practices into science and physics education have been especially influential in the laboratory physics community, where laboratory physics courses are being redesigned from the introductory [36, 37] to the advanced level [38, 39]. As an example, our large scale transformation of the introductory algebra-based physics lab sequence to center practices is described in Funkhouser et al. (2019) [40], which is reproduced in Ch 3.

## 2.3 Assessing Labs

The timeline here is relevant because it shows several themes of laboratory education that have been repeated for over a century. First, the stated goals of laboratory education in the sciences have always included practical skills related to the methods of doing science, even if at times they went under different names, for example inquiry/scientific skills and abilities. Though we now refer to them as scientific or physics practices, they have always been at least part of the stated goals of laboratory instruction. Second, although these have been the goals, we have been struggling to properly integrate and assess them for equally as long. Mann, in 1910, worried about our inability to use labs effectively [8]. In 1978, Bates pleaded with instructors to find ways to measure the effects they saw labs having on their students [9]. Most recently, in 2017, Wieman et al., in their review of the literature, determined that labs had no measurable impact on conceptual knowledge as measured by standard content assessments [41]. If the assessments are not measuring the impacts labs have on our students, either in their skills and practices, or in other not content related ways, then the clear path forward is to develop ones that do.

Some of these assessments do exist. There is the Colorado Learning About Science Survey in Experimental Physics (the E-CLASS), where attitudes and expectations about experimental physics are measured [1]. There is also the Physical Measurement Questionnaire (PMQ), which is used to assess students' procedural understanding in experimental physics [42, 43]. Walsh et al. recently produced the Physics Lab Inventory of Critical thinking (PLIC) [44]. However, examples of unique, large scale assessments of the impact of physics labs are scarce and more work is needed on how lab practices can influence the affective[1] dimension of learning.

There are many more small-scale studies providing evidence of the impacts of labs in science and physics education. It has been shown many times that laboratory and authentic experimental experiences have a positive impact on students' attitudes about science [13, 14, 15, 16, 17]. Several studies have shown the impact of ISLE on different scientific abilities, such as critical thinking, experimental design, scientific habits of mind, and formative assessment tasks to acquire and assess

[1]Related to emotions, beliefs, and attitudes of the learners, as opposed to conceptual learning.

scientific process abilities [34, 34, 45, 46, 47]. O'Neill and Polman (2004) found that authentic experimental experiences improved scientific literacy [48]. Holmes et al. (2015) saw sustained improvements of critical thinking skills in students who were initially instructed on specific aspects of said skills [49]. Even with these studies, the impacts of laboratories are a clearly understudied in the field of physics education. This is in spite of the fact that lab courses have been a hallmark of both science and physics education for over a century.

## 2.4 Perspectives on Physics Identity

There is no one true model of identity in the literature; instead the chosen model must be tested and justified within the goals and context of interest. Narrative identities as introduced by Sfard & Prusak (2005) define identity as the story someone tells about themselves, which changes based on context and who they are talking to [50]. Gee (2000) describes identity as being recognized as a certain 'kind of person.' This discourse identity is defined such that discourse is a specific way of acting, speaking, doing, etc. that would get you recognized as a certain 'kind of person' [51]. In this work we have chosen to utilize models of identity that center practices, models that will be further detailed below.

The models from Hazari (2010) [19] and Carlone & Johnson (2007) [20] have similar perspectives with a focus on competence, performance, recognition, and interest (as explicitly added to the model in Hazari (2010) [19]). Competence: How good a students is at skills that are valued in science, as defined by the broader culture or by the individual. Performance: the process of acting out the role of a scientist in the form of larger scientific presentations or day-to-day routine and how the student presents themselves as aligned with professional scientists. Recognition: both self recognition as a science person, and recognition from 'meaningful others'. Meaningful others are defined by community norms but the individual can also redefine whose recognition is meaningful to them. One cannot pull off being a particular kind of person (enacting a particular identity) unless one makes visible to (performs for) others one's competence in relevant practices, and, in response, others recognize one's performance as credible. Interest is self-evident, but is included because of its impact on persistence [18].

Another model of identity comes from the social theory of learning and communities of practice (COP) [52, 4]. Wenger (1999) states that identity is produced by experiences and participation in specific communities and describes identity in practice as engaging in practices that define a COP. Identity is lived, negotiated, social, a learning process, a nexus, and a local-global interplay. Lived because it involves participation and reification. Negotiated because it is always a work in progress and never permanent. Social because it is formed through participation in a COP. A learning process is a trajectory that incorporates the past and future to establish meaning in the present and creates coherence through time. A nexus in that people are members of multiple COPs and the differences must be continually reconciled. A local-global interplay due to the fact that one participates in a local COP but must also negotiate their connection to the broader world.

Irving and Sayre use the COP model of identity in their small-scale qualitative study of the process that students go through from identifying as a physics student to a physicist [53, 54, 55, 56]. They studied physics majors in upper division physics labs and how the students positioned themselves within the physics community in connection with the COP model of identity. They motivate their work on identity with a focus on the retention of people within the physics major in order to quell the dwindling of the physics community. They reference the influence that a subject-specific identity has on retention in that discipline [18] and the connection between identification with being a physicist and physics-specific career choices.

In their qualitative study of the process of identity transformation in undergraduate learning assistants in their undergraduate Learning Assistant (ULA) program, Close et al.(2016) [21] introduce an adaptation of the two previously presented models of identity, COP and the one used by Carlone & Johnson [20] and Hazari et al. [19]. Their goals in that small-scale study are to understand the experience of the ULAs, using identity as a lens. Close et al. define identity as making sense of how others see and react to us, including recognition as competent and valued. In their data this manifests for the ULAs in the ways in which they can impact and influence the students they are working with. The next part of the model is community membership combined with competence. Close describes this as competence developed and valued by members of the community. Community membership and competence showed up in the form of competence in teaching and understanding physics as well as the development of a community of physics ULAs and a connection with the broader physics community. Finally there is learning trajectory combined with interest. According to Close this incorporates past and potential future identities to make sense of the present. For the ULAs, participating in the program increased their interest in teaching and they viewed the experience as valuable for their future.

## 2.5 Classes as Communities of Practice

Irving and Sayre (2016) [56] argue that positive experiences with practices that are seen to be more legitimate and authentic can produce a change in identity status. This supports our goals to examine experiences with practices as a means to understand identity. In order to utilize a COP related model of identity in physics labs, it needs to be established that lab classes are COPs. In Irving (2014) [57] they describe the ways in which a lab course can become a community of practice. The concept of a classroom community as a community of practice is not a new one [58, 59]. But it is an effective way to examine the impacts an individual course can have. In Irving (2014) [57] they motivate the relevance of a lab class as a COP with the fact that "A community that has many similarities to that of a professional research environment provides the opportunity for students to recognize each other as more authentic physicists than before." This work further motivates the value of participating in authentic practices for students in developing a physics identity.

Although not all (maybe not even most) lab classes form communities of practices that effectively progress students toward central membership in the community of practicing physicists, they all have the potential to impact a student's relationship with physics [57]. Common practices are not the only things that make a community of practice, but they are a distinct feature and one that is often made more apparent in lab classes. The experiences the students have with those physics practices, in participation or in integrating them with those from other communities, provide us with information about their physics identity.

## 2.6 Decisions and Motivations for this Study

Grounding the study of identity in the COP model can allow for direct analysis of the impacts of a course or program has on an individual's subject-specific identity. For lab classes in particular it is relevant to look at the practices and skills valued in the course and how students position themselves with practices they perceive as important to the physics community, as indicated by their treatment in the course. For this reason physics lab classes with their emphasis on practices (both historically and more recently, including in our context) lend nicely to a COP-based model of physics identity.

In their work on identity, Close et al. [21] produced operationalized definitions of the different components of identity in the context of the ULA program, including a variety of examples from their data, which are utilized in the work described in this thesis. We chose this model because it led to clear and usable definitions of the components of identity allowing for adaptation into our context of interest.

As laid out previously, since their inception as tools of science education, labs have held skills and practices as a central goal. Most recently this goal has been reaffirmed (NRC and AAPT), which makes now the ideal time to both redesign labs with practices as a focus and assess the impacts of doing so. Additionally, an emphasis on practices has been found to impact students' attitudes [13, 14, 15, 16, 17] and development of a subject-specific identity [4, 54, 56].

The education community has always struggled with properly assessing the impacts of labs on our students, especially with large scale assessment tools [8, 9, 7, 41]. It makes sense to combine the study of how labs and practices impact identity with the development of a large scale assessment tool, meeting many of the aforementioned needs of the science education laboratory community in one assessment.

It is one thing to justify the use of an assessment, but it is another to justify the development of one. In the work done by Hazari et al. on identity, their analysis relies on the Persistence Research in Science and Engineering (PRiSE) survey [19]. The survey focuses on experiences students have in their high school physics and science courses, which does not allow for a focus on specific lab courses. Additionally, the framework used by Hazari et al. does not have the specific focus on practices, which is fundamental in the motivation of this work. There also exists an assessment of attitudes and expectations about experimental physics, the E-CLASS [1], and although the majority of the questions center on lab practices, only a handful of them relate in anyway to identity. In order to reach the goal of understanding the impact practices have on the identity development of students in physics lab classes inline with assessing the impacts labs themselves are having, a new assessment tool is required.

# CHAPTER 3

# DESIGN ANALYSIS TOOLS AND APPRENTICESHIP (DATA) LAB

The following chapter has been published in the European Journal of Physics [40] with minor modifications. It is published with co-authors William M. Martinez, Rachel Henderson, and Marcos D. Caballero.

## 3.1 Introduction

New knowledge in physics is driven by the observation of phenomena, the design of experiments to probe these phenomena, and the communication of and debate around the resulting measurements in public fora. Laboratory courses in physics are thus unique spaces where students can engage in these central aspects of studying physical systems. Greater emphasis on these aspects in laboratory spaces is needed to accurately represent the physics discipline and to engage students in the universal scientific endeavor that is driven by observation, measurement, and communication.

Recently in the United States, national calls have been made to design laboratory instruction such that it emphasizes students' engagement in experimental scientific practices rather than simply re-enforcing content learning [60, 11]. Such experiences would be better aligned with discovery-based learning [61], which is more representative of the enterprise of experimental physics. This focus on science practices is articulated in the American Association of Physics Teachers' *Recommendations for the Undergraduate Physics Laboratory Curriculum* [60]. These recommendations call for all laboratories in undergraduate physics to better represent experimental physics by constructing laboratory curriculum around science practices such as designing experiments, analyzing and visualizing data, and communicating physics. Arguably, middle-division and advanced laboratory courses for physics and astronomy majors – with their more complex experiments and equipment as well as their focus on the professional development of future physicists – tend to engage students with these practices.

By contrast, introductory physics laboratory courses tend to have more prescriptive and direct approaches to instruction. In these courses, students often follow a well-documented procedure and do not typically have opportunities to explore the observed phenomenon and the associated experimental work. At larger universities in the United States, these introductory laboratory courses are taught to thousands of students per semester, which makes these more direct approaches to instruction attractive as they are quite efficient. At many US schools, engineering students, physical science majors, and biological science students must pass these laboratory courses to complete their degree program. The scale of these course offerings provides an additional challenge to incorporating science practices. There are unique examples in the literature where students of introductory physics are engaged with scientific practices such as the Investigative Science Learning Environment (ISLE) [62], Student-Centered Activities for Large Enrollment Undergraduate Programs (SCALE-UP) [63] and Studio Physics [64]. However, these courses have the advantage of being taught to smaller population of students than most introductory laboratory courses, in the case of ISLE, or having an integrated "lecture" and a modified instructional space, in the case of Studio Physics and SCALE-UP, and thus can make use of greater instructional resources.

In this paper, we describe a stand-alone, introductory physics laboratory course sequence for biological science majors at Michigan State University (MSU) that was designed specifically to engage students in scientific practices through the work of experimental physics. Students learn to design experiments, analyze and visualize their data, and communicate their results to their peers and instructors. Design, Analysis, Tools, and Apprenticeship (DATA) Lab is unique in that it is was explicitly designed with the AAPT Lab Recommendations in mind. The sequence is a stand-alone mechanics laboratory (DL1) and a separate E&M and optics laboratory (DL2), which is taught to more than 2000 students per year. Furthermore, the process of developing and launching this pair of courses required that we confront and overcome several well-documented challenges such as departmental norms for the course, expectations of content coverage, and the lack of instructor time [65].

We begin this paper by describing how the learning goals for the lab sequence were constructed through a consensus-driven process (Sec. 3.2). In Sec. 3.3, we provide an overview of the course

Table 3.1: Finalized learning goals for DATA Lab

| Learning Goal | Description |
|---|---|
| LG1 - Experimental Process | Planning and executing an experiment to effectively explore how different parameters of a physical system interact with each other. Generally taking the form of model evaluation or determination. |
| LG2 - Data Analysis | Knowing how to turn raw data into an interpretable result (through plots, calculations, error analysis, comparison to an expectation, etc.) that can be connected to the bigger physics concepts. |
| LG3 - Collaboration | Working effectively as a group. Communicating your ideas and understanding. Coming to a consensus and making decisions as a group. |
| LG4 - Communication | Communicating understanding – of the physics, the experimental process, the results – in a variety of authentic ways – to your peers, in a lab notebook, in a presentation or proposal. |

structure – diving deeper into the details of the course materials later (Sec. 3.4). We describe the assessments for this course in Sec. 3.5 as they are somewhat non-traditional for a course of this level and scale. To make our discussion concrete, we highlight a particular example in Sec. 3.6. Finally, we offer a measure of efficacy using student responses to the Colorado Learning Attitudes about Science Survey for Experimental Physics [1] (Sec. 3.6) and some concluding remarks (Sec. 3.8)

## 3.2 Learning Goals

As this laboratory course serves the largest population of students enrolled in introductory physics at MSU, it was critical to develop a transformed course that reflected faculty voice in the design. While physics faculty are not often steeped in formal aspects of curriculum development, sustained efforts to transform physics courses take an approach where faculty are engaged in the process to develop a consensus design [66, 67, 41]. In this process, interested faculty are invited to participate in discussions around curriculum design, but experts in curriculum and instruction synthesize those discussions to develop course structures, materials, and pedagogy. These efforts are then reflected out to faculty to iterate on the process. Our design process followed the approach developed by the University of Colorado's Science Education Initiative [66, 67, 41]. In this process, faculty are engaged in broad discussions about learning goals, the necessary evidence to achieve the expected learning, and the teaching practices and course activities that provide evidence that students are meeting these goals. Below, we discuss the approach to developing learning goals for the course as well as present the finalized set of learning goals from which the course was designed. We refer readers to [41] for a comprehensive discussion of setting about transforming courses at this scale.

Prior to engaging in curriculum and pedagogical design, an interview protocol was developed by WMM to talk with faculty about what they wanted students to get out of this laboratory course once students had completed the two semester sequence. The interview focused discussion on what made an introductory laboratory course in physics important for these students and what role it should play as a distinct course since, at MSU, students do not need to enroll in the laboratory course at the same time as the associated lecture course. A wide variety of faculty members were interviewed including those who had previously taught the course, those who had taught other physics laboratory courses, and those who conduct experimental research. In total, 15 interviews were conducted with faculty. This number represents more than half of the total number of experimental faculty who teach at MSU.

The discussion of faculty learning goals was wide-ranging and covered a variety of important aspects of laboratory work including many of the aspects highlighted in the AAPT Laboratory Guidelines [60]. Interviews were coded by WMM for general themes of faculty goals and the initial list included: developing skepticism in their own work, in science, and the media; understanding that measurements have uncertainty; developing agency over their own learning; communicating their results to a wider variety of audiences; learning how to use multiple sources of information to develop their understanding; demonstrating the ability to use and understand equipment; documenting their work effectively; and becoming reflective of their own experimental work.

With the intent of resolving the faculty's expressed goals with the AAPT Lab Guidelines, the goals were synthesized under larger headings, which aimed to combine and/or to connect seemingly disconnected goals. In addition, through a series of informational meetings that roughly

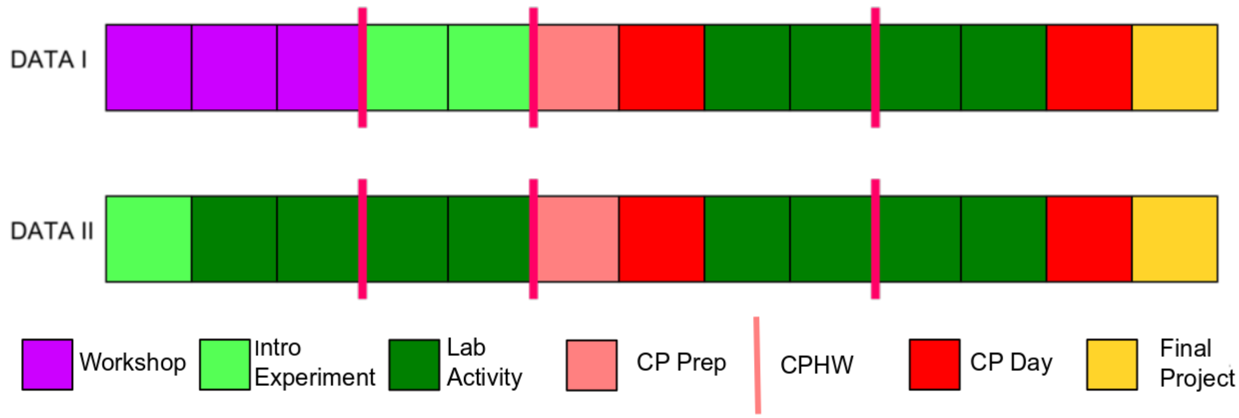



Figure 3.1: Week-by-week schedule of DATA Lab I & II.

10-12 faculty attended regularly, how these goals were being combined and connected to interested faculty were reflected upon. Additional critiques and refinements of these goals were collected through notes taken during these meetings. Through several revisions, a set of four broad goals that faculty agreed reflected their views on the purpose of this part of laboratory courses was finalized. Additionally, these goals were also represented in the AAPT Lab Guidelines. The finalized goals are listed in Table 3.1 along with short description of each; they are enumerated (LG*X*) in order to refer to them in later sections.

The learning goals formed the basis for the design of course structures including materials and pedagogy. To construct these course structures, constructive alignment [68] was leveraged, which helped ensure that the designed materials and enacted pedagogy were aligned with the overall learning goals for the course. These structures are described in the next section where we have included a direct reference to each learning goal that a particular course structure is supporting.

## 3.3 Course Structures

Each laboratory section consists of twenty students and two instructors – one graduate teaching assistant (GTA) and one undergraduate learning assistant (ULA) [69]. The students are separated into five groups of four, which they remain in for 4 to 6 weeks – 4 to 6 class meetings. This time frame works well because it gives the students time to grow and improve as a group as well as individuals within a consistent group. In addition, when the groups are switched it requires the students to adapt to a new group of peers. The groups complete 6 (DL1) or 5 (DL2) experiments during the semester, most of them spanning two weeks – two class meetings. Fig. 3.1 provides an overview of the two-semester sequence and will be unpacked further below. We indicate the laboratories that students complete with light green squares (introductory experiments) and dark green squares (two week labs). The students keep a written lab notebook, which they turn in to be graded at the end of each experiment. In this laboratory course, each group conducts a different experiment. This is possible because, in general, students tend to follow a similar path with respect to the learning goals and there is no set endpoint for any individual experiment. As long as students continue to work through the experimental process and complete analysis of their data, they are working towards the learning goals and can be evaluated using the aligned assessments (Sec. 3.5). This approach also emphasizes that there is not one way to complete an experiment; this has added benefits for students' ownership and agency of the work as they must decide how to proceed through the experiment. In addition, having no set endpoint and two weeks to complete most experiments takes away the time pressure to reach a specific point in a given time. All of these aspects allow students to more fully engage with the work they are doing and, in turn, make progress toward the learning goals. Having each group conduct a different experiment addressed a significant point of discussion among the faculty; specifically, not covering the same breadth of content was a major concern. Although, through this design, students do not complete all of the experiments, they are introduced to all of the concepts through the peer evaluation of the communication projects (red squares in Fig. 3.1, addressed in detail below).

### 3.3.1 Laboratory Activities

The laboratory activities were designed around the learning goals. As such, the experiments follow a similar path from the beginning of the experimental process through analysis, with communication and collaboration as central components throughout. The course structures in relation to each of the learning goals are highlighted below. The core component (i.e. lab activities) of the course sequence is outlined in Fig. 3.2.

**LG1 - Experimental Process:** The students begin each experiment by broadly exploring the relevant parameters and their relationships. Typically, students investigate how changing one parameter affects another by making predictions and connecting their observations to physics ideas (qualitative exploration in Fig. 3.2). From these initial investigations, students work toward designing an experiment by determining what to measure, change, and keep the same. This often requires grounding decisions on some known model or an observed relationship (quantitative exploration, experimental design, and investigation in Fig. 3.2).

**LG2 - Data Analysis:** After additional formal investigations in which data has been collected, students summarize the raw data into an interpretable result. This typically includes some form of data analysis; for example, constructing a plot to evaluate a model or determining a quantitative relationship between the different variables in the data. In this work, the students are expected to make claims that are supported by their results. This often involves the students finding the slope and/or intercept in a plot and interpreting those results with respect to their expectations (discussion and analysis in Fig. 3.2).

**LG3 - Collaboration:** Throughout the experimental work and analysis, students discuss and make decisions with their peers in their lab group. Students are encouraged to develop a consensus approach to their work – deciding collectively where to take their experiment and analysis. Furthermore, students are expected to make these decisions by grounding their discussions in their experiment, data, and analysis.

**LG4 - Communication:** Overall, the entire process requires that students communicate with their group and instructors. Additionally, students communicate their experimental approach and the results of their work including their analysis in their lab notebook. Later, students provide a more formal presentation of their work in the form of the communication projects.

It be should emphasized that this process is not content dependent; each laboratory activity conducted by a student group follows this process. This generalization enables the core components

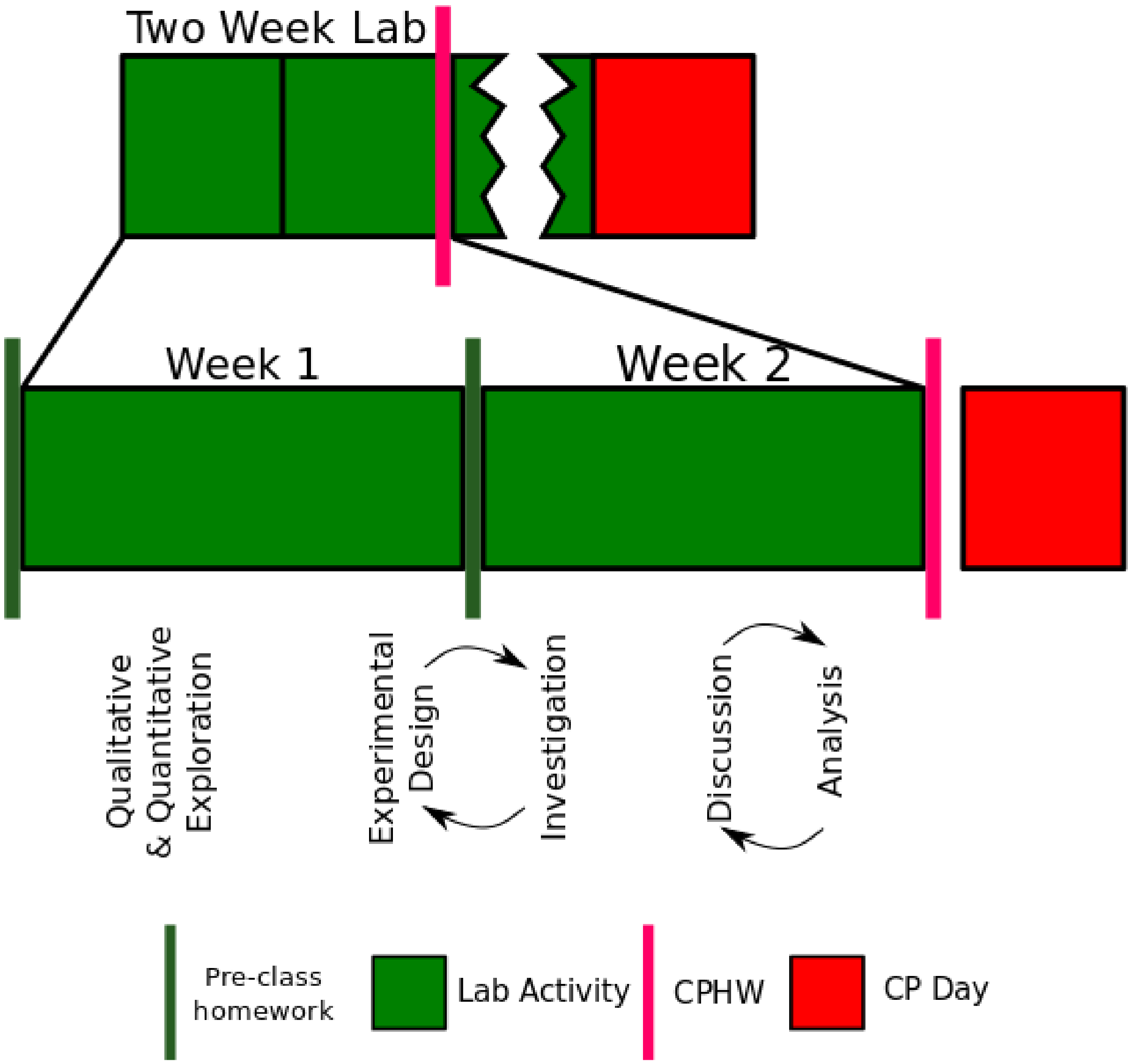



Figure 3.2: A snapshot of an experiment from pre-class homework through the communication project.

of the course to be repeated (see Fig. 3.1) to help address external constraints, such as limited equipment and time to work on experiments.

### 3.3.2 Communication Projects

DATA Lab is also defined by the focus on authentic scientific communication through the communication projects (CPs). The CPs are a formal way for the students to present their work and they are one of the assessments of the course in which the work done by the students is completed individually. CPs replace the lab practical from the traditional version of the course where students would conduct a smaller portion of a laboratory by themselves. CPs occur in the middle and at the end of the semester (red squares in Fig.3.1). In DL1, the CP is a written proposal that summarizes the work the students conducted in one of their previous experiments and proposes an additional investigation. In DL2, the students create and present a research poster on one of (or a portion of one of) their experiments. In both courses, the projects are shared with and reviewed by their primary instructor and their peers in the class.

Through the CPs, students continue to engage with the faculty consensus learning goals (Sec. 3.2) as described below:

**LG1 - Experimental Process:** Students are expected to reflect on and summarize the process through which they went to complete the experiment. In so doing, they must communicate their rationale and reasoning for following that process.

**LG2 - Data Analysis:** The students must show that they can turn their raw data into an interpretable result. Again, this is often and, ideally, done in the form of a plot of their data with the emphasize of a model, including a fit, is needed. Students also present and explain what the results mean in the context of the experiment and a physical model.

**LG3 - Collaboration:** While the experiment was completed with the student's group where they may have consulted with their group mates, the CPs themselves are not inherently collaborative. However, in DL1, the reviews that students perform on each other's projects are done collaboratively in their groups.

**LG4 - Communication:** The CPs are the formal communication of a student's experimental work. In both courses, a student's CP is reviewed by their peers and feedback is provided describing successes and shortcomings along with suggestions for improvements.

### 3.3.3 Final Projects

The course structure was designed with the intent to provide students with a variety of ways to engage in the experimental physics practices. The final projects are an additional form of communication including an analysis and interpretation of experimental results through critiquing other scientific results (DL1–Critique Project) and describing a new experimental design (DL2–Design Project).

*Critique Project*: For the final project in DL1, students critique two sides of a popular science topic. In the prior week, students are arranged into new groups and before the class meeting, they must choose, as a group, from a list of possible topics such as climate change and alternative energy. In class, students collectively write up a summary and critique both sides of the scientific argument.

*Design Project*: For the final project in DL2, students choose an experiment that was conducted previously and design a new experiment for a future semester of DATA Lab. Similarly to DL1, the students are sorted into new groups and they must decide, as a group, which experiment they will be working on before the class meeting. Due to the structure of the course, specifically everyone doing different experiments throughout the semester, this choice may be an experiment that individual members of the group did not complete; negotiating this decision is part of the process of the Design Project. In class, students construct two documents: (1) a document that explains the design of the new experiment and (2) a document that would aide a future DATA Lab instructor to teach the experiment. Through this final project, DL2 students can design a project covering material that they may not have had the chance to explore during the course.

For both final projects, students turn in one assignment per group and they receive a single grade (as a group) for the assignment. Students also assess their own in-class participation, providing themselves a participation score (on a 4.0 scale) for the day. This score is submitted to their instructor along with their rationale for assigning themselves the grade.

These projects offer the final opportunity for DATA Lab students to engage with the faculty-consensus learning goals:

**LG1 - Experimental Process:** In DL1, students evaluate and summarize both sides of the chosen argument by reviewing the relevant data and experiments. Although students are not conducting an experiment, they are still asked to be critical of the experimental process in each side of the argument. In DL2, students must create a clear procedure for their proposed experiment. Here, they must consider the available equipment as well as how the data would be collected and why.

**LG2 - Data Analysis:** In DL1, the students must evaluate the evidence provided in each article. They must decide if there are obvious flaws in the way the analysis was conducted and if the analysis is compelling; that is, if the overall claims made in article align with the data and analysis. In DL2, students must consider the kind of analysis that would fit with their experiment and the data that they would collect. In addition, students are also expected to reflect on their analysis in light of the models that are available to explain the data they would collect.

**LG3 - Collaboration:** In both courses, students continue to work as a group and are graded accordingly. In addition, the students have been put into new groups, which they must adjust to.

**LG4 - Communication:** In both courses, students continue to communicate with their group as part of the collaboration. In DL1 specifically, the final project provides an opportunity to communicate their own evaluation and critique of a scientific arguments. Students in DL2 are expected to communicate to different audiences, including future DATA Lab students and instructors, about their newly planned experiment.

## 3.4 Overview of Key Supports

As the students' work in this course is sufficiently open-ended, specific supports to ensure they feel capable of conducting the lab activities have been designed. Since the CPs are the main assessments in the DATA Lab course sequence and are a large portion of their overall grade for the course, the goals of the key supports are intended to provide students with the tools to help them succeed in the projects. Each of the supports designed for DATA Lab will be discussed in detail below (Secs. 3.4.1 & 3.4.2). Assessments will be discussed in Sec. 3.5 (also in Appendix B).

Broadly, the key supports for the students are outlined in Fig. 3.2. Before each class day, students complete a pre-class homework assignment (vertical green lines). Students also have three communication project homework (CPHW) assignments during the semester (vertical pink line) to help them complete their CPs. These supports, in addition to feedback on students' in-class participation and lab notebooks, apply for any of the regular two week experiments (green squares Fig. 3.1). In the following section, these will be described in detail along with the additional supports that were designed for the courses.

### 3.4.1 Typical Experiment

Each two-week experiment follows a similar path, highlighted in Fig. 3.2 and described, in part, in Sec. 3.3. In this section, details of the general course components necessary to maintain the flexibility of the path students take through each experiment will be described.

**Pre-Class Homework:** At the beginning of an experiment, students are expected to complete the pre-class homework assignment which includes reading through the lab handout and investigating the suggested research. This assignment is usually 2-4 questions designed to have students prepare for the upcoming experiment. For example, before the first day of a new lab, students are asked what they learned during their pre-class research and if they have any questions or concerns about the lab handout. Between the first and second class meeting of the two-week experiment, students are expected to reflect on what they have already done and prepare for what they plan to do next. Typically, the 2-4 questions include reflections from the prior week, such as any issues their group ran into on the first day, and what they intend on doing during the second day of the experiment. Answers to the pre-class homework serve as additional information that the instructors can draw on during the class; knowing what questions and confusions that their students might have can help instructors be more responsive during class. Overall, the goal of the pre-class homework is for the students to come into class prepared to conduct their experiment and this assignment is used to hold them accountable for that preparation.

**In-class Participation**: With the overall intent of improving students' specific laboratory skills and practices that are outlined in the course learning goals (Sec. 3.2), students receive in-class participation grades and feedback after every lab section (green squares in Figs 3.1 & 3.2) on their engagement with respect to these practices. As the lab handouts do not provide students with specific steps that they must take to complete the experiment, students are expected to make most of the decisions together as a group. Generally, students have control over how their investigation proceeds; however, this control varies between experiments (i.e. students choose how to set up the equipment, what to measure, how to take measurements, etc.). The in-class participation grades and feedback are where students are assessed most frequently and where they have the quickest turnaround to implement the changes. See Sec. 3.5.1 for the details of how in-class participation is assessed.

**Lab Notebooks**: For each experiment that the students engage in, they are expected to document their work in a lab notebook. In comparison to formal lab reports, lab notebooks are considered a more authentic approach to documenting experimental work. Furthermore, lab notebooks provide students with space to decide what is important and how to present it. The lab notebooks are the primary source that the students use to create their CPs. Like in-class participation, students receive lab notebook feedback much more regularly than CP feedback, so they have greater opportunity to reflect and make improvements. The specific details of the assessment of lab notebooks will be explained in Sec. 3.5.1.

**CP Homeworks:** Three times during the semester the students complete CPHW assignments in addition to that week's pre-class homework. Each CPHW focuses on a relevant portion of the CPs (e.g., making a figure and a caption). Through the CPHWs, the aim is for students to develop experience with more of the CP components. In addition, students receive feedback on these different aspects (see Sec. 3.5.1) , which they can act upon before they have to complete their final CPs.

**Communication Projects:** Throughout each semester, the students complete two CPs, the first of which is a smaller portion of their overall course grade. With the goal of providing the students with a second opportunity to conduct a CP after receiving initial feedback, this course design feature intends to create less pressure on students during their first CP assignment. Students are expected to reflect on the process, their grade, and the feedback before they have to complete another CP. The CP assessment details will be discuss further in Sec. 3.5.2.

### 3.4.2 Additional Supports

Along with the support structures for the core components of the course sequence, additional supports have been designed to ease students into the more authentic features of DATA Lab such as designing experiments and documenting progress in lab notebooks. DL1 begins with three weeks of workshops (purple squares in Fig. 3.1), followed by the introductory experiment (light green squares in Fig. 3.1) that all of the students complete. DL2 begins with an introductory experiment as well, under the assumption that the students already went through DL1. The workshops and introductory experiments are designed to assist the students in navigating the different requirements and expectations of the overall course sequence, and of a typical experiment within each course. The additional support structures are described in detail below.

**DL1 Workshops:** The first workshop focuses on measurement and uncertainty with a push for the students to discuss and share their ideas (LG1,3). The students perform several different measurements – length of a metal block, diameter of a bouncy ball, length of a string, mass of a weight, and the angle of a board. Each group discusses the potential uncertainty associated with one of the measurements. Then, students perform one additional measurement and assign uncertainty to it. The second workshop also focuses on uncertainty but in relation to data analysis and evaluating models (LG2,4) using the concept of a spring constant. Students collect the necessary measurements, while addressing the associated uncertainty and plot the measurements to analyze how the plot relates to the model of a spring. The final workshop focuses on proper documentation. The lab handouts do not contain their own procedure, so each student is expected to document the steps they take and their reasoning (LG4) in their lab notebook. In preparation for the third workshop, as a pre-class homework, students submit a procedure for making a peanut butter and jelly sandwich, which they discuss and evaluate in class. Students are then tasked with developing a procedure to determine the relationship between different parameters (length of a spring and mass added, angle of metal strip and the magnets placed on it, or time for a ball to roll down a chute and how many blocks are under the chute). At the end of each workshop the students turn in their notebooks, just as they would at the end of any experiment.

**Introductory Experiments:** In DL1, the introductory experiment occurs after the three workshops. All students conduct a free-fall experiment where they must determine the acceleration due to gravity and the terminal velocity for a falling object. In DL2, the introductory experiment is the first activity in the course. This is because students will have already completed DL1 prior to taking DL2; rather than being slowly introduced to what DATA Lab focuses on, students can be reminded in a single experiment. The introductory experiment for DL2 involves Ohm's Law; students must determine the resistance of a given resistor.

As these are the first DATA Lab experiments for either course, the instructors take a more hands-on and guiding approach than they will later in the semester. In DL1, these instructional changes represent a dramatic shift from the guidance students had during the workshops where instructors are often quite involved. In DL2, the one week lab is intended to be simple enough that students can be reminded of the expectations with respect to the overall learning goals of the course.

**CP Prep Day:** As discussed in the prior section, the CPs comprise a large portion of the students' total grade in the course. In addition to the supports that were already mentioned – in class grades, notebooks, CPHW, and a lower stakes CP1 – in the spring semester, the MSU academic calendar offers time for a communication project prep day (pink squares in Fig. 3.1). This gives the students an extra day where they have time to work on their CPs in class. They can take additional measurements, seek help from their group or instructor, or work on the project itself. This prep day allows for a gentler transition into the CPs with a bit more guidance. It also reduces the amount of work that the students have to do outside of class.

## 3.5 In Course Assessments

The DATA Lab activities described above were designed around the overall learning goals outlined in Sec. 3.2. As such, the course assessments were also aligned with these overall course goals. There are two types of assessments used in DATA Lab – formative (to help the students improve upon their work) and summative (to evaluate the students' output); these are separated for clarity. In this section, the various assessment tools are discussed with respect to the overall learning goals of the course. (All rubrics are included in Appendix B).

### 3.5.1 Formative Assessments

In DATA Lab the formative assessments are comprised of students' work on their in-class activities, lab notebooks, and CPHWs. Other than the pre-class homework, which is graded on completion, there is a rubric for each activity for which students receive a score. Each is structured to ensure that any improvements students make carry over to their CPs.

**In-class Participation**: In-class participation feedback is broken into group, which covers the general things everyone in the group or the group as a whole needs to work on, and individual, which is specific to the student and not seen by other group members. The general structure of the feedback follows an evaluation rubric used in other introductory courses and focuses on something they did well, something they need to work on, and advice on how to improve [70]. It is expected that students will work on the aspects mentioned in their prior week's feedback during the next week's class. Students are graded based on their response to that feedback. Any improvements they make with respect to the learning goals in class will also likely impact how well they complete their CPs.

Students' in-class participation is assessed with respect to two components, group function and experimental design. Specifically, group function covers their work in communication, collaboration, and discussion (LG3,4). For communication they are expected to contribute to and engage in group discussions. To do well in collaboration, students should come to class prepared and actively participate in the group's activities. Discussion means working as a group to understand the results of their experiment. Experimental design evaluates the process that students take through the experiment and their engagement in experimental physics practices (LG1,2). They are expected to engage with and show competence in use of equipment, employ good experimental practices (i.e., work systematically, make predictions, record observations, and set goals) and take into account where uncertainty plays into the experimental process (i.e., reduce, record, and discuss it).

Specifically for the DL1 Workshops, instructors grade students differently than they would for a typical experiment. The emphasis for the workshops is on the group function aspect of the rubrics, communication and participation. This is because the students are being eased into the expectations that the instructors have around experimental work.

**Lab Notebooks**: Feedback and grades for lab notebooks are only provided after the experiment is completed (the two week block in Figs 3.1 & 3.2). Students receive individual feedback on their notebook, although members of a group may receive feedback on some of the same things simply because they conducted the experiment together. Like for in-class participation, it is expected that the students will work on the aspects mentioned in their feedback for the next lab notebook and the instructor can remind them of these things in class during the experiment.

Lab notebooks are also graded over two components, experimental design and discussion. Experimental design focuses on the experimental process and how students communicate it (LG1,4). Here, instructors typically look for clearly recorded steps and results, and intentional progression through the experiment. Discussion covers uncertainty in the measurements and the models, as well as the results, with respect to any plots and conclusions (LG2,4). These evaluation rubrics for the lab notebooks were designed to be aligned with the those for the CPs, so that when students work toward improving their notebooks they are also making improvements that will benefit their CPs. For example, if a student is getting better at analyzing data and communicating their results within their notebooks, instructors should expect the same improvement to transfer to their CPs.

For the DL1 Workshops, the lab notebooks are graded on the same components but the grades and feedback are specifically focused on the parts of the rubric that the students should have addressed in each of the previous workshops. For example, as documentation is emphasized in the last workshop, the students are not heavily penalized on poorly documented procedures in the first two workshops.

**CPHW**: The goal of this CPHW is to have students think about creating a more complete CP that connects their in-class work to the bigger picture. Students are evaluated on the quality and relevance of their sources, including the background and real-life connections (LG2,4). Each CPHW has a different rubric because each one addresses a different aspect of the CPs. *Figure and caption*: The students create a figure with a robust caption based on the data from one of the labs they completed. Both the figure and the caption are evaluated on communication and uncertainty (LG2,4). For the plot, the students are expected to visualize the data clearly with error bars and it should provide insight into the various parameters within the experiment. For the caption, students need to discuss what is being plotted, make comparisons to the model including deviations, and draw conclusions that include uncertainty.

*Abstract*: For a given experiment, students write a research abstract that covers the main sections of their project including introduction, methods, results, and conclusion. These are assessed on experimental process (motivation and clarity of the experiment) (LG1,4), and discussion (results and conclusions) (LG2,4).

*Critique (DL1 only)*: Students are given an example proposal that they must read, critique, and grade. This assignment plays two roles. First, students must examine a proposal, which should help to produce their own. Second, students must critique the proposal, which should help them provide better critiques to their peers. Students' performance is evaluated based on their identification of the different components of a proposal, and the quality of the feedback they provide (LG4).

*Background (DL2 only)*: Students are tasked with finding three out-of-class sources related to one of their optics experiments, which they must summarize and connect back to the experiment.

### 3.5.2 Summative Assessment

The CPs form the sole summative assessment of student learning in DATA Lab. As described above, each of the formative assessments are designed to align with the goals of the CPs.

**CPs**: As mentioned above, although students conduct the experiments together, the CPs are completed individually. In DL1, students' CP is a proposal that emphasizes their prior work and discusses a proposed piece of future work. As a result, the CP rubric is divided into two sections, prior and future work. Within those sections, there is a focus on experimental design and discussion. This rubric was iterated on after piloting the course for two semesters as it was found that students would often neglect either their future work or prior work when they were not directly addressed in the rubric; the rubrics were reorganized in order to account for this. Experimental design, which covers methods and uncertainty, focuses on the experimental methods and the uncertainty in measurements, models, and results when students discuss their prior work (LG1,2,4). In future work, experimental design refers to the proposed experimental methodology and the reasoning behind their choices (LG1,4). For the student's discussion of prior work, the rubric emphasizes how the they communicate their results (LG2,4). When students discuss their future work, the rubric emphasizes the novelty of the proposed experiment and the arguments made on the value of the project (LG1,4).

In DL2, students' CP is a poster that they present to their classmates for peer review. The rubric includes an additional component on the presentation itself, but the rubric still emphasizes the experimental design and discussion. Experimental design covers communication of the experimental process including students' reasoning and motivation. Discussion focuses on the discussion of uncertainty (i.e., in the measurements and models) and the discussion of results (i.e., in the plot and conclusions). The additional component focusing on presentation is divided into specifics about the poster (i.e., its structure, figures, layout) and the student's presentation of the project (i.e., clear flow of discussion, ability to answer questions).

## 3.6 Example Experiment

Overall, the course structures, supports, and assessments of DATA Lab have been discussed. In this section, the key supports will be grounded in examples from a specific experiment. The details of a specific two-week experiment will be described to better contextualize the features of the course. Additional experiments are listed in Tables A.1 and A.2 in Appendix A. The chosen experiment is from DL2 and is called "Snell's Law: Rainbows." In this experiment, students explore the index of refraction for different media and different wavelengths of light.

Before attending the first day of the laboratory activity, students are expected to conduct the pre-class homework assignment, including the recommended research in Fig. 3.3. In addition, the homework questions for the first day of a new experiment address the pre-class research, as follows:

**Research Concepts**

To do this lab, it will help to do some research on the concepts underlying the bending of light at interfaces including:

- Snell's Law (get more details than presented here)
- Refraction and how it differs from reflection
- Index of refraction of materials
- Fiber optics
- Using this simulation might be helpful: http://goo.gl/HEflDI
- How to obtain estimates for fits in your data (e.g., the LINEST function in Excel - http://goo.gl/wiZH3p)

Figure 3.3: Pre-class research prompts for the Snell's Law lab.

1. Describe something you found interesting in your pre-class research.

2. From reading your procedure, where do you think you may encounter challenges in this lab? What can you do to prepare for these?

3. Considering your assigned lab, is there anything specific about the lab handout that is unclear or confusing?

**Part 1 - Observing Light in Water**

At your table, you have a tank of water and a green laser. Turn on the green laser and point it at the water's surface.

- What do you notice about the beam of light in the water?
- What about the path the light takes from the source to the bottom of the tank?

Let's get a little quantitative with this set up. Can you measure the index of refraction of the water? You have a whiteboard marker, a ruler, and a protractor to help you. Don't worry about making many measurements, just see if you can get a rough estimate by taking a single measurement.

- What does your setup and procedure look like for this experiment?
- What part(s) of your setup/procedure is(are) the main source of uncertainty for this measurement?
- Can you gain a sense of the uncertainty in this measurement?
- How close is your predicted value to the "true value" of the index of refraction of mater?

---

On the optical rail you have a half circle shape of acrylic that is positioned on a rotating stage, with angular measurements. You also have a piece of paper with a grid attached to a black panel (i.e., a "beam stop"). Using this setup, you will test Snell's Law for the green laser. Your group will need to decide how to set up your experiments and what measurements you will make. You should sketch the setup in your lab notebook and it would be good to be able to explain how your measurements relate to Snell's Law (i.e., how will the laser beam travel and be bent by the acrylic block?). In conducting this experiment, consider,

- What measurements do you need to make?
- What is the path of the laser beam and how does it correspond to measurements that you are making?
- What is a good experimental procedure for testing Snell's Law?
- What kind of plot is a useful one to convey how the model (Snell's Law) and your measurements match up?
- Where is the greatest source of uncertainty in your experimental setup? What does that mean about the uncertainty in your measurements?

Figure 3.4: Snell's Law: Rainbows Lab Handout. *Top*: Exploring refraction, first day of Snell's Law. *Bottom*: Beginning model evaluation, main Snell's Law activity.

The first day of the lab begins with exploring refraction in a water tank. Students are asked to qualitatively explore the index of refraction of the water using a simple setup (Fig. 3.4). The exploration is fully student led; they investigate the laser and tank, discussing what they see with their group as they go and recording their observations in their notebooks. Students observe that the path of the light changes once the laser crosses the air-water boundary. Students are then lead to a quantitative exploration by determining the index of refraction of the water; instructors expect the students to have an idea of how to do this after their pre-class research. If students are not sure how to start, they are encouraged to search for Snell's Law online where they can quickly find a relevant example. The instructors check in with the students toward the end of this work. Typically, instructors will ask about the questions outlined in the lab handout.

The next part of the experiment is where students work to gain precision in their measurements and evaluate the model of the system. This part is most similar to a traditional laboratory course. The difference is that the students are told the goal but not how to proceed (see Fig. 3.4). There are a number of decisions they must make as a group as they progress. Students record and explain their decisions in their lab notebooks; they might also discuss them with their instructor.

Typically by the end of the first day students know how to set up their experiment and have documented that in their lab notebooks. They are unlikely to have taken more than one measurement (the design and investigation phase in Fig. 3.2). They will return the following week to complete their experiment. The homework questions between the first week and the week that they return emphasize students' reflections on the previous week. Students also are asked think about the experiment outside of class. The typical homework questions prior to Week 2 are the following:

1. Because you will be working on the same lab this week, it is useful to be reflective on your current progress and plans. Describe where your group ended up in your current lab, and what you plan to do next.

2. Now that you are halfway through your current lab and are more familiar with the experiment, what have you done to prepare for this upcoming class?

3. Describe something that you found interesting in your current lab and what you would do to investigate it further.

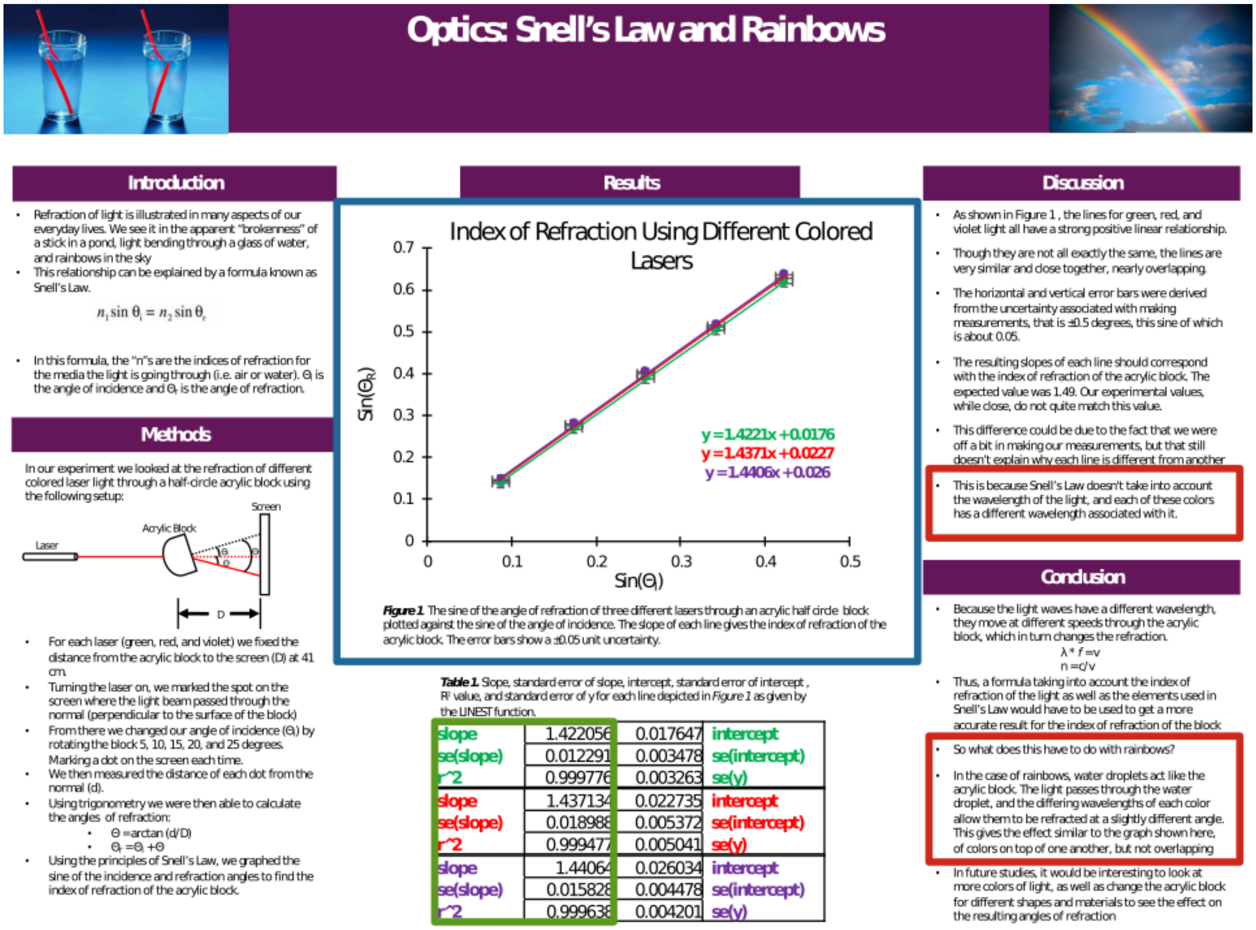



Figure 3.5: Sample of a student's Communication Project for DL2. *Blue*: graph with sine of the angle of incidence plotted against sine of the angle of refraction for each wavelength of light. *Green*: The slope for each wavelength, which is the index of refraction of the block. *Red*: Results and conclusions where they discuss the differences in the indices of refraction and how that is related to rainbows.

The second week starts with setting up the experiment again and beginning the process of taking multiple measurements. At this point, students often break up into different roles: someone manipulating the equipment, one or two people taking measurements, and someone recording the data and/or doing calculations. These roles are what students appear to fall into naturally, and are not assigned to them. Although, if one student is always working in excel or always taking the measurements, instructors will address it in their feedback where they encourage the students to switch roles.

The next step depends on the amount of time that students have left in the class. If there is not much time, students focus on the data from one wavelength of light. If they have more time, they can make the same measurements with lasers of different wavelengths. In both cases, students can determine the index of refraction of the acrylic block. With multiple wavelengths, students are able to see that the index of refraction depends on wavelength. This leads to a conversation with the instructor about how this relates to rainbows and a critique of the model of refraction – Snell's Law.

Most of the analysis that students conduct in this example experiment is the same regardless of how many lasers they collected data (discussion and analysis in Fig. 3.2). While considering the different variables in their experiment, students are expected to make a plot where the slope tells them something about the physical system. In this case, the design is intended for the students to plot the sine of the angle of incidence on the x-axis and the sine of the angle of refraction on the y-axis, which makes the slope the index of refraction of the acrylic block. The optics experiments occur in the second half of the semester after the students have become familiar with constructing linear plots from nonlinear functions. For this lab, students usually do not have much difficulty determining what they should plot. After they obtain the slope and the error in the slope, students will typically compare it to the known index of refraction of the acrylic block. They must research this online as it is not provided anywhere for them in the lab handout.

The second day of the experiment ends with a discussion of their plot. Students construct a conclusion in their notebooks that summarizes the results, what they found, what they expected, reasons for any differences, and an explanation of what it all means in the larger physics context.

After the experiment, the students may have their third and final CPHW, background/literature review. In the case of Snell's Law, students would be asked to find three additional sources where these concepts are used in some other form of research, often in the field of medicine but also in physics or other sciences. Students then summarize what they did in class and connect their experimental work to the sources that they found.

The student can choose to do their second CP on this experiment. An example of a poster can be seen in Fig. 3.5. In the figure, three key features are highlighted. First, in the blue box, is the graph where students plotted all three wavelengths of light. In the green box, is the slope for each color, which is the index of refraction of the acrylic for each laser. Finally, in the red boxes, are their results and conclusion. In the top box, students explained why their indices are different, that is, because of the assumption that Snell's Law is wavelength independent. In the bottom box, they make the connection to rainbows. The student would present this poster during the in-class poster session, to their peers and their instructor.

## 3.7 Redesign Efficacy

To measure the efficacy of the DATA Lab course transformation, the Colorado Learning Attitudes about Science Survey for Experimental Physics (E-CLASS) [1] was implemented in the traditional laboratory course as well as the transformed courses. The E-CLASS is a research-based assessment tool used to measure students' epistemological beliefs, specifically students' views about learning experimental physics, and their overall expectations about a course designed around experimental physics [1, 71, 72, 73]. This instrument was designed to probe various aspects of experimental physics and although it has been recommended that 'instructors should examine their students' responses to the questions individually with a particular focus on those questions that are most aligned with their learning goals for that course' [71], here, we will report student outcomes on the overall instrument. Future research will include analyzing student responses to the E-CLASS items in connection to the specific learning goals described in Sec. 3.2.

The well-validated survey consists of 30 items (5-point Likert scale) where students are asked to rate their level of agreement with each statement. The scoring method of this assessment was adapted from previous studies [74]. First, the 5-point Likert scale is compressed into a 3-point scale; "(dis)agree" and "strongly (dis)agree" are combined into one category. Then, student responses are compared to the expert-like response; a response that is aligned with the expert-like view is assigned a $+1$ and a response that is opposite to the expert-like view is assigned a $-1$. All neutral responses are assigned a 0.

In DL1 and DL2, the E-CLASS was administered as an online extra credit assignment both pre- and post-instruction. Throughout the course transformation, DL1 and DL2 collected a total

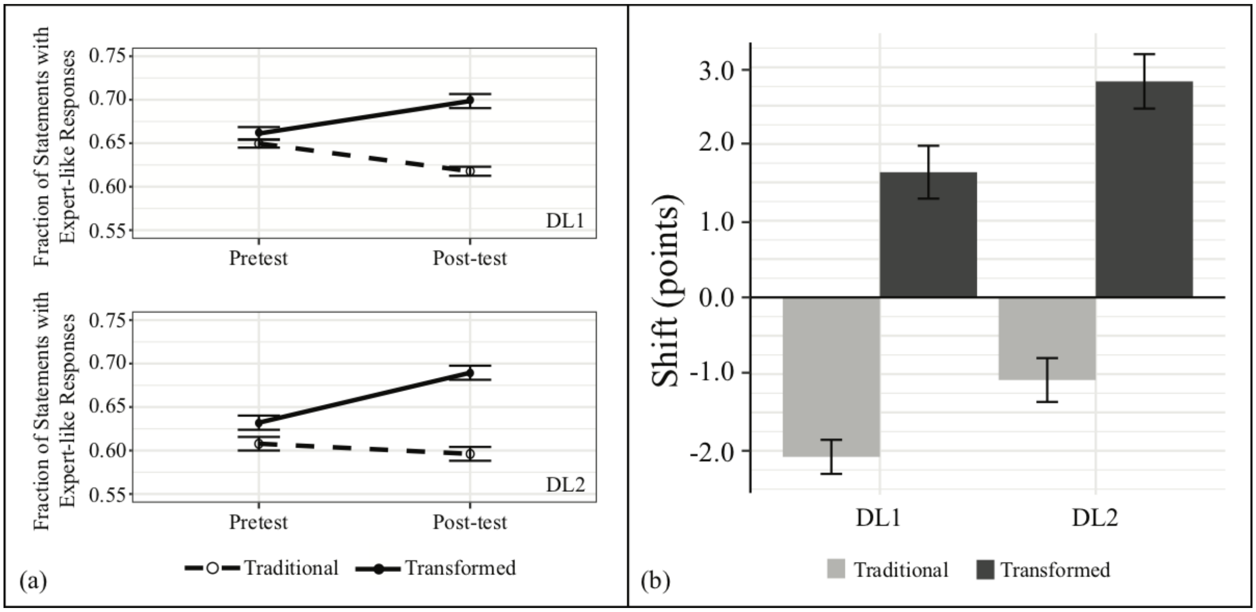



Figure 3.6: Comparing student E-CLASS outcomes between the traditional course and the transformed course: (a) Fraction of statements with expert-like responses as presented in Zwickl *et al.* [1] and (b) Shifts in student expert-like thinking from pretest to post-test as presented in Wilcox and Lewandowski [2].

number of responses from 1,377 and 925 students, respectively, with matched (both pretest and post-test) E-CLASS scores. Fig. 3.6 presents two of the most common ways that E-CLASS scores are reported. Here, the overall results between the traditional course and the transformed course will be compared. Fig. 3.6(a) illustrates the fraction of statements with expert-like responses from pretest to post-test, which was introduced in the initial E-CLASS manuscript [1]. Fig. 3.6(b) illustrates the overall shift in students' expert-like thinking from pretest to post-test which has been a more recent way of representing overall E-CLASS results [71, 2].

As shown in Fig. 3.6(a), the fraction of E-CLASS statements with expert-like responses in the traditional courses significantly decreased ($ps \ll 0.001$) by 3% in DL1 and by 1% in DL2 from pre- to post-instruction. However, in the transformed courses, the fraction of expert-like statements increased by 4% and by 6% in DL1 and DL2, respectively ($ps \ll 0.001$). In reference to the analysis method presented by [1], the DATA Lab course transformation showed a significant positive impact on the fraction of statements on the E-CLASS with expert-like responses.

Fig. 3.6(b) shows that, in both of the traditional courses, students' overall expert-like thinking decreases significantly ($ps \ll 0.001$) from pre-instruction to post-instruction, specifically by 2.1 points ($pre$ = 14.4 points, $post$ = 12.3 points) in DL1 and 1.1 points ($pre$ = 12.5 points, $post$ = 11.4 points) in DL2. However, in both DL1 and DL2, there was a significant positive shift ($ps \ll 0.001$) in students' expert-like thinking, 1.6 points ($pre$ = 14.9 points, $post$ = 16.6 points) and 2.8 points $pre$ = 14.3 points, $post$ = 16.1 points), respectively. Overall, the DATA Lab course transformation showed a significant positive impact on students' expert-like thinking toward experimental physics.

## 3.8 Conclusion

In this paper, the large scale transformation of the MSU algebra-based physics labs for life science students was described. The design was divorced from the specific physics content because the learning goals developed from a faculty consensus design did not include specific content. This design means that the individual lab activities do not matter *per se*, but instead the structure of the course and how students work through the lab are what is important. Theoretically, one could adapt this design to a chemistry or biology lab by making adjustments to the kinds of lab activities, and relevant changes to the learning goals. That being said, there are still key structures to ensure the functioning of the course which will be covered in detail in a subsequent paper (e.g. a leadership team of four instructors, two GTAs and two ULAs, tasked with maintaining consistent grading and instruction across the sections).

The transformation was centered to emphasize experimental physics practices. The overall efforts were focused on the two course series because the majority of the students that are taking courses in the physics department at MSU are enrolled in the introductory algebra based series, specifically 2,000 students per year. In addition, the majority of the student instructors in the MSU physics and astronomy department, nearly 80 graduate teaching assistants and undergraduate learning assistants, teach in these labs. Because of its scale, special attention was given to the voice of the physics faculty in the development of the learning goals for DATA Lab [41]. The entire course was designed around the faculty-consensus learning goals, which are all based around physics laboratory practices (Sec. 3.2). From course structures to assessments, everything was intentionally aligned with the overall learning goals. Each component of the course builds upon another through the two semester sequence. Each individual lab activity builds upon skills that will be valuable for each subsequent activity, from lab handouts to pre-class homework assignments. Such an effort was put into designing this course sequence in large part because of the number of MSU undergraduate students they are serving. The value in physics labs for these non-majors lies in the scientific practices on which the redesign was centered. Those skills and practices are what they will take with them into their future careers.

CHAPTER 4

# IDENTITY

## 4.1 Introduction

Laboratories are a hallmark of science education and have been for over a century [23]. These tools of science education provide students with opportunities to engage in the process of 'doing science,' i.e., in the skills and practices relevant to applying the scientific method. Physics education, along with other fields of science education, has not always been successful at taking advantage of this opportunity. Introductory labs, for example, are often still prescribed step-by-step experiments with goals limited to understanding content. Lab courses have been found to add little to no benefit in content and conceptual goals [10, 11]. Instead, designing lab courses to emphasize the unique opportunity provided for engagement in skills and practices necessary to do science has recently become a focus thanks to the Next Generation Science Standards (NGSS) and the American Association of Physics Teachers (AAPT) committee on laboratories [12, 5]. Both have pushed for a focus in science and physics laboratory education to better represent experimental science and physics. Upper level physics labs are more often structured this way than introductory ones, but the skills and practices are just as relevant in both stages. This is true for physics majors as well as other STEM majors. In either case, we want students to come out of our physics courses knowing what it means to do physics.

Engagement with the practices of the physics community is necessary in the process of identifying with the community [4, 53, 55, 56]. The fact that lab classes, especially recently, are a space for this type of engagement implies that they are also spaces where identity development is likely happening. Field specific identity has been found to impact persistence and retention in the major [18], choice of major and future career [75], and to be linked to underrepresentation in the field [20, 19]. It could be argued that the value in physics identity development only applies to students within the physics major but at many large institutions the dominant population of students served are non-physics STEM majors. There are two main reasons why it is necessary to care about the impact on their identity in this case. First, it is important to do well by the largest population of students that our departments serve. Doing right by them in the case of lab courses is providing them with authentic experiences in doing experimental physics. Second, the skills and practices that are valued in physics are also relevant in other STEM fields.

In this study we provide a starting point for investigating identity development in lab classes as connected to the practices emphasized in those courses at a large scale. This is part of our work on developing a survey to measure physics identity in lab classes. Physics labs and authentic experiences are relevant for all STEM students, from upper division physics majors to introductory non-physics majors. The push to include authentic experiences with practices in physics laboratory education solidifies these practices as a relevant and impactful aspect of these courses and in turn motivates us to ground our study of physics identity in the specific valued practices of the field. In this paper, we introduce a theoretical framework that ties identity and laboratory practices together, and then demonstrate the applicability of this framework through the coding analysis of 15 interviews and 140 open-ended written responses. We will demonstrate through this data and analysis that we can use a practice based identity framework in laboratory classes. We also call for additional work on the components of identity that are assessable in these settings.

In the following sections we first justify the relationship between labs, practices, and identity from the existing literature (Sec. 4.2). We then describe the data sources and methods used in our investigation (Sec. 4.3). Following that, in Sec. 4.4, we describe the analysis process and present the results of that analysis. Finally we discuss the outcome of the adaptation of the combined framework in our context and the implications of this work (Sec. 4.5).

## 4.2 Theoretical Background

We start out by grounding the motivation of our work in the literature. This section includes a discussion of evidence for the prevalence of practices as central goals in science laboratory education for over a century. There is a look at the work done showing how experiences in labs and with lab practices work to produce attitudinal changes. Those changes can be connected to some of the literature on physics identity. We highlight how practices may impact identity and the framework being adapted is introduced. The work presented here is focused on adapting the combined identity framework as introduced in Close et al, 2016 [21] (and described below).

### 4.2.1 Lab Practices

Historically laboratories have been an integral piece of science education. “The laboratory has won its place in school; its introduction has proved successful. It is designed to revolutionize education. Pupils will go out from our laboratories able to see and do” (Griffin 1892, cited by [6, 7]). The process and practices that go along with it have also been a valued part of scientific education. In the 1960s the ‘discovery-based learning’ movement lead to inquiry as a way to learn scientific content [27, 25, 26]. The goals of both inquiry and laboratory education at the time are reflective of what we now refer to as science practices. The goals include: communicating [28], analyzing data [29], planning and executing experiments [28, 24, 29], and understanding equipment [28, 30], in addition to inquiry skills [31] and the scientific method [24].

In the late 1990s a focus was again placed on inquiry in science and physics education through the publication of the National Science Education Standards [32]. After this came the development of ISLE (Investigative Science Learning Environment) with their emphasis on scientific abilities [34, 35, 45]. They define scientific abilities as “the most important procedures, processes, and methods that scientists use when constructing knowledge and when solving experimental problems” [35].

Most recently the American Association of Physics Teachers released their recommendations for undergraduate physics labs: six focus areas all emphasizing practices [5]. In addition to that the Next Generation Science Standards address experimental and lab practices [12]. In response to this, the field has shifted the focus of lab courses to make practices and skills, not just a benefit of labs, but a central focus of the design of these courses [40, 38, 76, 77, 78, 39, 37, 79, 80, 81].

The literature shows that this emphasis on practices also translates to attitudinal changes.

Bechman [17] and Ergül [15] found that experiences with lab and research practices improved attitudes about science. Others have found that authentic experiences with practices increase interest in science and in science careers, and that students find practical activities more enjoyable [82, 16]. Although there has been work showing these positive effects of experiences with lab practices, there have not been large scale studies. In addition, the assessment tools to do that are limited. As of this writing, there is one such tool that measures attitudes and expectations in physics laboratories, the Colorado Learning about Sciences Survey in Experimental Physics (E-CLASS) [1]. There is still a void in the literature, especially when it comes to specific attitudinal and affective measures, which is why we have been working to develop an assessment that measures the impact experiences with lab practices have on a students' physics identity. The full survey development is not the focus of this paper, instead we will focus on the analysis specific to understanding and analyzing physics identity in lab classes.

### 4.2.2 Physics Identity

As part of introducing the identity framework used in this research, several perspectives on identity are defined and discussed. One way to look at physics identity is highlighted in Hazari et al., 2010 [19]. In that work they analyzed responses to the Persistence Research in Science and Engineering (PRiSE) survey. The elements they focused on for their analysis broadly focused on high school physics experience and were correlated with an item that stated "I see myself as a physics person." Hazari defines physics identity with four components: competence, performance, recognition, and interest. Recognition is mainly perceived recognition from parents or peers. Interest refers specifically to interest in physics, coming from the fact that affect has a large impact on persistence. Competence and performance are connected: competence is belief in one's ability to understand the science content and performance is belief in one's ability to perform tasks. In the study Hazari et al. found recognition had the largest effect on physics identity.

According to Wenger [4] identity is solidified through participation in specific communities and it is produced by lived experiences in those communities. Identity is lived, negotiated, social, a learning process, a nexus, and a local-global interplay. Lived because it involves participation and reification. Negotiated because it is always a work in progress and never permanent. Social because it is formed through participation in a COP. A learning process because it is a trajectory that incorporates the past and future to establish meaning in the present and creates coherence through time. A nexus in that people are members of multiple COPs and the differences must be continually reconciled. A local-global interplay due to the fact that one participates in a local COP but must also negotiate their connection to the broader world.

Close et al. [21] combine the four components from Hazari et al. with multiple aspects of COP and identity formation in a study of how identity development is impacted by participation in an undergraduate learning assistant (ULA) program. Close et al. condensed the above mentioned definitions of identity into four combined components. The first is negotiated experience from COP combined with interest from Hazari et al.. They define this as making sense of how others see and react to us, including recognition as competent and valued. In their data this manifests for the ULAs in the ways in which they can impact and influence the students they are working with. The next is community membership combined with competence. This is described as competence developed and valued by members of the community. This showed up in the form of competence in teaching and understanding physics as well as the development of a community of physics ULAs and a connection with the broader physics community. Then is learning trajectory combined with interest. According to Close et al. this incorporates past and potential future identities to make sense of the present. For the ULAs, participating in the program increased their interest in teaching and they viewed the experience as valuable for their future. Finally there is the nexus of multimembership combined with an integrated physics identity, such as incorporating practices and values from different communities. This is evidenced by the ULAs having increased competence in one community from experience in another, the ULA community and the larger physics community.

### 4.2.3 Labs as Communities of Practice

As stated in Wenger [4] identity development happens through authentic participation in a specific community. This refers specifically to participation in practices that are valued by a community. In Irving [57] they describe the ways in which a lab course can become a community of practice. The concept of a classroom community as a community of practice is not a new one [58, 59]. But it is an effective way to examine the impacts an individual course can have. Irving et al. [57] motivate the relevance of a lab class as a COP with the fact that "A community that has many similarities to that of a professional research environment provides the opportunity for students to recognize each other as more authentic physicists than before." This motivates further the value of participating in authentic practices for students in developing a physics identity.

Although not all (maybe not even most) lab classes form communities of practices that effectively progress students toward central membership in the community of practicing physicists, they all have the potential to impact a student's relationship with physics [57]. Common practices are not the only things that make a community of practice, but they are a distinct feature and one that is often made more apparent in lab classes. The experiences the students have with those physics practices, in participation or in integrating them with those from other communities, provide us with information about their physics identity.

Irving and Sayre [56] argue that positive experiences with practices that are seen to be more legitimate and authentic can produce a change in identity status. This supports our goals to examine experiences with practices as a means to understand identity. We may be able to catch a snapshot of the exploration described in Irving [56].

Grounding identity in communities of practice provides tangible elements that can influence a student's identity. One can determine if they are given the opportunity to perform practices, if they know the practices at all, if they are recognized by the community, if the accepted practices are at odds with some other part of their identity, which may be particularly relevant for non-physics majors in physics lab classes. With this as a motivator and lab classes as the COP of interest, we worked to apply the combined Close framework as an operationalized definition of physics identity.

We only utilized three of the four components described above. We left out the component focused on the nexus of multimembership and an integrated physics identity not because it is incorrect, but because the component of learning trajectory and interest covers this to the extent that it is relevant to this stage of the work, as we will describe below.

## 4.3 Methods

Before it can be determined whether or not the Close framework can be applied to this context the following question must be answered: "How is identity development connected to the valued practices within the laboratory physics community?" The literature provides support for the claim that these two things are connected but evidence of how they are connected is the goal of this study through the development of a detailed codebook. First interviews were conducted with students in introductory and upper division physics labs. Then an open-response survey was distributed in order to determine if the results from the interviews were representative of the broader population.

### 4.3.1 Interviews

The first step in operationalizing the connection between identity and lab practices was to interview students about their experiences in physics lab classes in order to better understand how they interacted with and interpreted the practices that were emphasized in the lab. Fifteen students were interviewed about their experiences in the physics labs they were currently enrolled in. Six students were physics majors or minors in upper level optics or the advanced lab. Nine students were in the introductory algebra-based labs for non-majors, four in the transformed version of the EM course (Ch 3) and five in the traditional version of the mechanics course.

The fifteen semi-structured interviews followed the same general structure (see Appendix C for interview protocol). The students were asked about their past physics lab experience and their current lab course. Once the background was established, they were asked to define several different lab practices in the context of their physics lab class. Most participants were also asked to compare this to any other lab experiences they may have had (e.g., earlier physics labs, chemistry and biology labs). After they provided their interpretation of the practice in their physics labs, they were asked whether or not they found that application of the practice valuable. They were specifically asked about how valuable they found these practices, while keeping 'valuable' open to interpretation, because of the connection to the practices valued in a specific community and the potential impacts on identity development, especially with respect to integrating overlapping identities.

### 4.3.2 Interview Analysis Methods

The interviews were analyzed through open coding[1] of recordings of the interviews. The majority of the coding was done using the qualitative analysis software, MAXQDA, directly on the video. The primary focus of the analysis was developing a representative understanding of the different interpretations of the physics practices. Through the analysis, the different ways the practices were described by the students were determined and were used in the open-response survey. The secondary analysis of these data focused on operationalizing the connection of these practices to identity statements and finding examples of how students make identity statements in connection to the practices.

### 4.3.3 Open-Response Survey

In order to determine if the working definition of identity from the interviews was broadly applicable, an open-response survey was distributed to get more student responses. Each question for the open-response survey had four parts, two closed- and two open-response. The closed response questions were Likert scale with the same structure 'This practice is important...' they then have two responses to this 'For ME' and 'For an EXPERIMENTAL PHYSICIST.' (See Fig. 4.1 with survey example) We asked for both responses because, like the ECLASS [1], during beta tests of the survey the participants were uncertain if they should answer based on their own personal thinking or based on the 'correct' answer. This structure enabled us to pay specific attention to the students' personal

[1] Sorting responses into specific categories that come out of the analysis and are not based on a specific theoretical framework.

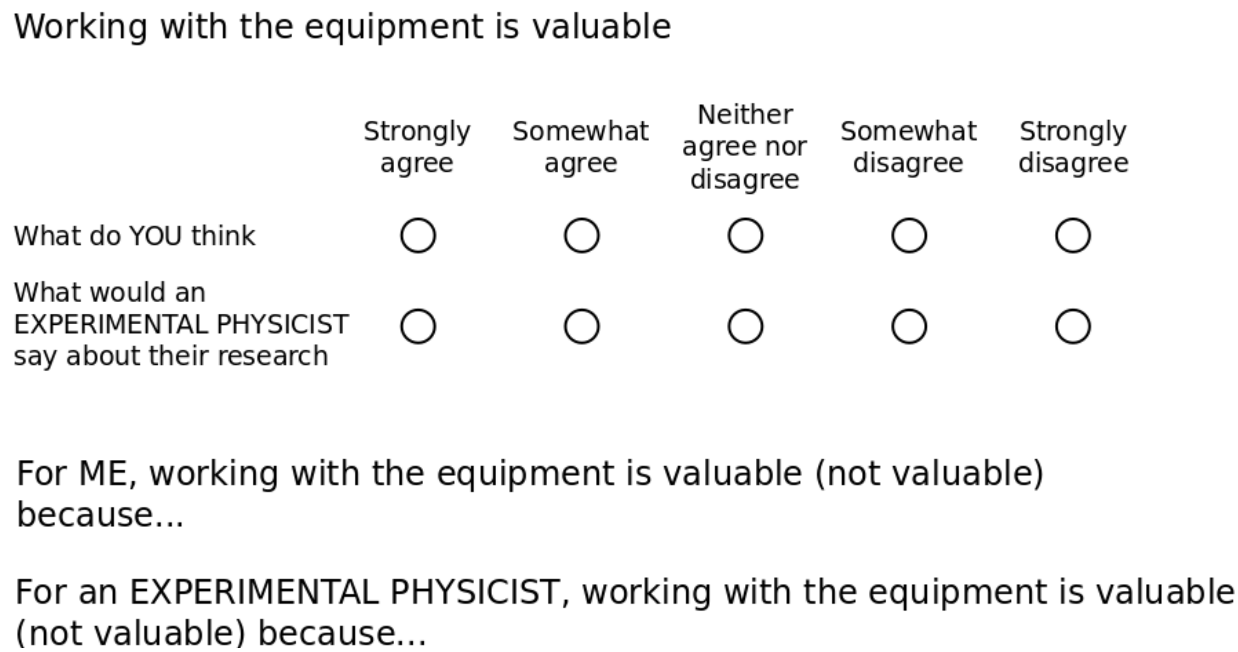



Figure 4.1: Example question from the open-response survey

responses with potential different avenues of analysis available with the responses specific to the experimental physicist (or 'expert') questions. The practice specific questions, 108 in total, were also developed from the interviews. The process is described in Chapter 5. The next two questions were free-response, and developed with the goal that the students would supply an explanation or justification as part of identity statements that could be coded. Those questions were, 'For ME, this practice is important (not important) because...' and the same thing but 'For an EXPERIMENTAL PHYSICIST.' An example question is shown in Fig. 4.1.

The open-response survey was distributed via Qualtrics[2] at the end of the spring semester 2018, to a transformed introductory algebra-based physics lab for non-physics majors with 640 students. Responses from approximately 500 students were collected, a 78% response rate. Each student received a randomly selected set of ten of the 108 practice questions, in the format shown and described above. As compensation for completing the survey, the students were given a small amount of extra credit added to their in-class participation scores. The high response rate is attributed in part to the extra credit but also to in-class advertising that the graduate teaching

[2]Qualtrics, 2019, Qualtrics Labs, Inc. Provo, UT, USA

assistants and undergraduate learning assistants that teach the course conducted in response to a request from the developer, and the lead teaching assistant at that time.

### 4.3.4 Survey Analysis Methods

The primary analysis was focused on the questions that referenced what the students personally thought and not what they thought an 'expert' would think (e.g. the responses to 'for ME' and not 'for an EXPERIMENTAL PHYSICIST'). Based on the initial coding of identity in the interview analysis, the results from the open-response survey were analyzed for identity in parallel with work that focused on practice-specific interpretations. From that subset and the interviews, initial definitions for the components of the identity framework were established and they were sorted according to emergent themes. Then the emergent codes were compared to the Close et al. framework. The codes were reduced to parallel those used by Close et al. and then the operationalized definition was validated with an external researcher. The researcher was provided with a codebook and an initial teaching set of twenty responses to code in the different identity components, followed by forty additional training responses. The coding of the final set of responses (representing 25% of the total data) was used in the calculation of interrater reliability. The researcher was given responses that were already determined to be identity, and was instructed to code each response in whole into one of the identity components. This additional validation was required to confirm that the different responses could be reliably coded (with a Cohen's Kappa reliability measure of 0.92 (near perfect agreement) [83, 84]) and as added confirmation of the interpretation of evidence of the components in the data.

## 4.4 Results and Analysis

### 4.4.1 What Makes an Identity Statement

Before any work could be done utilizing the Close model of identity, a definition of identity in this context was needed. Each example of an identity statement discussed has a connection to a specific lab practice as aligned with the goal of connecting experiences with lab practices to

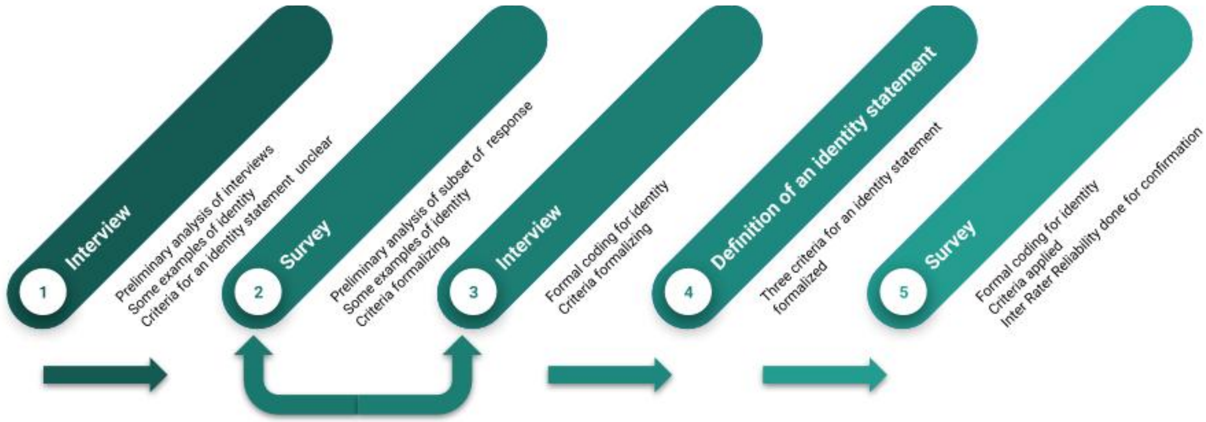



Figure 4.2: Figure showing process of determining what makes an identity statement

physics identity. This definition was developed through the different stages of the analysis. The first requirement is that the statement must connect to a lab practice. This requirement is in connection with the claim that practices can impact identity and with the goals to examine that connection in lab classes through the development of a survey. We cannot claim the origin of any statement regarding identity unless it is clearly grounded within the context of interest, lab classes and practices. The next requirement is based on the literature that an identity statement would be a personalized statement of the value of the practice. With those two pieces of the definition in mind, the interviews were analyzed for examples of these personalized value statements connected to the lab practices. Several potential identity statements from the interviews were discussed with experts on identity and other qualitative research methods [85]. From the consultation with experts, it was further established that in order for a statement to be counted as identity it needs to be personalized. It was also determined that in addition to the personalization, there needs to be an explanation or justification for the personalized value statement, e.g. ‘this practice is important to me because of this reason.’ The following examples highlight the criteria at this stage and work to provide insight into the development of three specific criteria described at the end of this section (see Fig. 4.2).

Table 4.1: What makes an identity statement? These examples are used to aid in answering that questions. Ex 1-3 come from the interviews and Ex 4-7 come from the open-response survey.

| **Data** | | **Analysis** | | |
|---|---|---|---|---|
| Label | Response | 1. Connected to a practice | 2. Contains a value statement | 3. Has an explanation or justification for value statement |
| Ex 1 | **Blake** (discussing uncertainty): "[...] I do understand its importance, and see it as a necessary thing. It's just, I personally will never really need to take uncertainty as seriously as it is taken in these upper-level lab classes and...I don't look at it the same way as someone who's thinking 'I want to do experimental physics for the rest of my life'". | Analyzing data with a focus on uncertainty | *I do understand its importance, and see it as a necessary thing.* | *personally will never need to take uncertainty as seriously* and *don't look at it the same way as someone who plans* a future in experimental physics. |
| Ex 2 | **Adam:** I really enjoy it, I enjoy working on something and feeling like you're making progress. It's not like following the steps and you end up where you're supposed to end up, right? So um I guess it gives a sense of possession and a sense of accomplishment to actually do something because you weren't just gifted it. | Executing an experiment | *'I really enjoy it, I enjoy working on something* | – |
| Ex 3 | **Beth** (describing something she found exciting): "It was good to, plug it all into the calculator and [see] this is a reasonable answer. So, getting something that...could be right and doing that without a procedure is more self-satisfying because...you relied more on yourself" | Analyzing data through calculations | – | – |
| Ex 4 | **Q:** Determining patterns from my data is important. **A:** it is not so important to look for trends in data because overall it is only a small part of what I am studying for my degree and will not necessarily help me in my overall career. | Analyzing data by looking for trends | *it is not so important.* | *small part of what I am studying. . . in my overall career.* |
| Ex 5 | **Q:** Communicating my results by answering specific questions is important **A:** It helps me keep track of what I'm doing but sometimes the organization demanded in class isn't realistic for real life. | Communicating results | *it helps me...* | *organization demanded...not realistic* |
| Ex 6 | **Q:** Letting each group member have hands-on time with the equipment is important. **A:** It can help everyone and if they need to use it in the future. | Working in a group | *It can help everyone.* | *if they need to use it in the future.* |
| Ex 7 | **Q:** Doing calculations with data is important. **A:** data collection is your main source of information in an experiment and you should use your personal data to complete calculations. | Analyzing data | – | – |

The first example discussed is Ex 1 from the "What makes an identity statement" table (Table 4.1). Here Blake is talking about the practice of analyzing data with a focus on uncertainty. He mentions the importance and necessity of the practice, which are both statements about the value of the practice. Blake then qualifies the value statement by saying that due to his future outside of experimental physics he will not need to use uncertainty and therefore he does not find it personally valuable.

In Ex 2, Adam is describing the process of executing an experiment. He highlights the value of that practice by describing his preference for it with the use of "enjoy." The rest of the quote, provides many examples of positive affect. It could be argued that tying in agency in the mention of possession and accomplishment implies identity but agency does not explicitly fit into the model of identity being tested, although there is work that suggests a connection [86, 87]. In addition, we are looking for self-contained identity statements, in order to make claims about the connection between practices and identity. At this stage this example from Adam does not qualify as identity within the established criteria.

Ex 3 is Beth describing analyzing data through calculations in her physics lab. She provides examples of positive affect, 'more self-satisfying,' that in and of itself is not an identity statement. It could be qualified as a value statement if Beth were to include an explanation or justification for why she values things that are self-satisfying. Or, using another example from her, she could also have made a similar qualification to the value of self-reliance. As with Adam, this example from Beth does not meet the requirements of an identity statement as established thus far.

This is not to say that these examples from Beth and Adam are not indicative of identity, they likely are. It is also not the responsibility of the student to independently explain their reasoning and provide us with perfect, self-contained examples of identity statements. But, in the process of this work, we are only looking for self-contained statements in order to develop a codebook to test the combined identity framework and to highlight the connection between practices and identity. All three quotes are evidence of a connection between experience with lab practices and different measures of affect (e.g., identity, self-reliance, and agency).

The survey questions were designed based on the initial criteria for an identity statement, where the closed response questions contained the connection to the practice and the value statement (see Fig. 4.1). The open-response portion was where students explained their reasoning for their answer to the previous question with the goal of producing further examples of identity to solidify the criteria. Responses to survey questions are assumed to be personal unless they explicitly state otherwise (e.g. 'This is important for everyone'). This is because the open-response questions are already personalized within the question statement, 'For ME this is (not) important because...'

Breaking down Ex 4, the practice is analyzing data by looking for trends, which is included in the question statement and the response. The value statement could be taken from the question but the student provides it in their response, when they say it is not important. Then they justify their value statement by connecting to their future career. In Ex 5 the practice is communicating results. They establish value by mentioning how it helps them. Then they qualify that adding that the organization required by the course is unrealistic. Both of these are examples of identity, they are connected to a practice, contain a personal value statement, which is justified.

In Ex 6, the practice is working in a group, which is pulled from the question statement. There is a value statement that is not personalized, describing how it is valuable for everyone. Additionally, the justification is not personal to the student. This example is not an identity statement because it is lacking personalization in both the discussion of the value and the justification. In Ex 7 the practice is analyzing data, they also mention data collection in executing experiments. This is simply a description of the practice, it does not contain any personal connection to the practice or any further justification.

The above seven student quotes are used to highlight the determination of the requirements for an identity statement in this work on labs, practices, and identity. Each example of an identity statement discussed has a connection to a specific lab practice as aligned with the goal of connecting experiences with lab practices to physics identity. After initial analysis of the open-response questions for identity, and an additional examination the potential statements from the interviews was done. Through this semi-iterative process, the operationalized definition of an identity statement was finally articulated. 1. It must discuss a practice (From our goals and in connection to the context). 2. It must contain a personalized value statement (From the literature and from expert consultation). 3. It must include an explanation or justification for the value statement (From the analysis of interviews and open-responses as well as from expert consultation).

Once the criteria for an identity statement was established we worked to connect and reduce the emergent codes in parallel to the work done by Close et al.

Table 4.2: Examples of LT responses from the data. LT1 is from the interviews and LT2-4 are from the open-response survey.

| **Learning Trajectory (LT)** statements are defined as when the value they put on the practice is connected to their future or their planned career | | | | | |
|---|---|---|---|---|---|
| **Data** | | **Analysis** | | | |
| Label | Response | 1. Connected to a practice | 2. Contains a value statement | 3. Has an explanation or justification for value statement | Explanation |
| LT 1 | **Blake** Yeah, So I think just based on wanting to be a teacher I see that as more valuable than someone who maybe just wants to understand physics for themselves because if you just want to understand physics for yourself you don't really care about you being able to communicate results to others, ... whereas I aspire to ... allow my understanding to feed understanding of others and to help develop their own... and so I think it's it's even more important to me to be able to communicate my results than others. | communicating, specifically communicating results | *I see that as more valuable . . . I think it's it's even more important to me.* | *based on wanting to be a teacher.* | he finds this practice valuable because of the goals he has for his future as a teacher. |
| LT 2 | **Q:** Determining patterns from my data is important **A:** it is not so important to look for trends in data because overall it is only a small part of what I am studying for my degree and will not necessarily help me in my overall career. | Analyzing data by determining patterns from data | *not so important* | *small part ... not necessarily help with my overall career* | This connects to their future with the discussion of their career |
| LT 3 | **Q** Working with the equipment is valuable **A:** It helps build confidence in doing hands-on things somewhat, but I don't think working with this specific equipment is really helpful for me in the future. | Executing experiments, specifically working with the equipment | *I don't think ... is really helpful for me* | *in the future* | They justify their value statement based on their future |
| LT 4 | **Q:** Working with the equipment is valuable **A:** I may never see this equipment again, and if I were to go to a lab the equipment and how it is used may be very different. learning the specifics of the equipment used may not be helpful, but it is valuable to understand what it does and why you would use it for the study. | Executing experiments, specifically working with the equipment | *may never see ... again* and *may not be helpful* | *I may never see this ... again* | This statement of the practice not necessarily being relevant for them going forward is what makes it an example of LT. |

Table 4.3: Examples of Interest statements from the data. Int 1 is from the interviews and Int 2-3 are from the open-response survey

| **Interest** statements are an indication of personal interest or preference for something. They are either statements that specifically mention interest or enjoyment of something or they show a positive or negative preference | | | | |
|---|---|---|---|---|
| **Data** | | **Analysis** | | |
| Label | Response | 1. Connected to a practice | 2. Contains a value statement<br>3. Has an explanation or justification for value statement | Explanation |
| Int 1 | **Fern:** especially if I don't understand what the results mean. Cause that's the part where I'm like, this makes total sense, this is really cool now, I can see this in my normal life. Connecting the dots is what makes science enjoyable to me | Communicating results | *what makes science enjoyable to me* | The value she sees in this practice comes from the enjoyment she gets out of it, which connects to the idea of preference in statements of interest. |
| Int 2 | **Q:** Presenting what my results mean is important **A:** I am not really into physics so I could care less if I present the data that I find because most the time I don't even understand it. | Communicating results | *not really into physics...could care less* | This is an example of negative preference |
| Int 3 | **Q:** Presenting what my results mean is important **A:** I don't love physics, so I don't love presenting the work, but it is important to receive peer feedback. | Communicating results | *I don't love physics...I don't love presenting work* | Two negative preference statements |

Table 4.4: Examples of NE from the data. NE 1 is from the interviews and NE 2-5 are from the open-response survey.

| **Negotiated Experience (NE)** statements are about dealing with (or adapting to) the expectations and values of the experimental physics community and negotiating how those values and expectations align (or not) with one's own. | | | | | |
|---|---|---|---|---|---|
| **Data** | | **Analysis** | | | |
| Label | Response | 1. Connected to a practice | 2. Contains a value statement | 3. Has an explanation or justification for value statement | Explanation |
| NE 1 | **Blake:** The process of executing the procedure and then like trying ... It's important in that I need to do it. I think because this class is so much more based on the data, I think the data collection takes precedent but I think also there are questions within the lab that do drawback to those exploring observations. So I think I value both of those. But mostly because the class values them. | Executing experiments | *it is important...I value* | *it is important in that I need to do it I value both of those ... because the class values them* | The value that Blake places on this practice is based on the requirements of the course. The intrinsic value he sees only goes as far as his connection to the course. |
| NE 2 | **Q:** Knowing how to adapt equipment to new situations is useful **A:** As a student I feel like this is not as important because most experiments I will do in a lab class will be controlled. This might be useful for the future but as of now I don't think it is necessary. | Understanding equipment, adapting it to new situations | *not as important might be useful* | *I don't think it is necessary* | |
| NE 3 | **Q:** Presenting what my results mean is important *A:* Typically, all of the results from DATA Lab experiments are inconsequential in a larger physics picture. Maybe it is somewhat helpful in understanding the lab, but it is not the most important part of an entire process for students. | Communicating results | *maybe somewhat helpful* | *inconsequential ... not the most important part* | 'inconsequential' indicates tension, 'maybe somewhat helpful' indicates value vs seeing value |
| NE 4 | **Q:** Interpreting graphs to understand relationships between parameters is important **A:** Not important because I don't like graphs and I feel obligated to make one even when I don't understand the concepts very well. | Analyzing data by interpreting graphs | *not important* | *I feel obligated* | They specifically describe feeling obligated |
| NE 5 | **Q:** Communicating my results by answering specific questions is helpful **A:** It helps me keep track of what I'm doing but sometimes the organization demanded in class isn't realistic for real life. | Communicating results | *It helps me* | *organization demanded ... isn't realistic* | Obligation in 'demanded' and tension in 'not realistic' |

Table 4.5: Example of a CM statement from the data. This example is from the open-response survey.

| **Community Membership (CM)** statements are where the value of the practice comes from the community. This can look like a distinction between communities or the value of something in one community versus another. | | | | | |
|---|---|---|---|---|---|
| **Data** | | **Analysis** | | | |
| Label | Response | 1. Connected to a practice | 2. Contains a value statement | 3. Has an explanation or justification for value statement | Explanation |
| CM 1 | **Q:** Explaining how I did what I did is important **A:** Because when performing an experiment of any sort you need to be detailed in order to be able to recreate the experiment exactly and reproduce the results. Or conversely to be able to go through and alter the procedure and check for flaws that could prohibit the results you hypothesize. This is true in any science and good practice even in physics. | Communicating results by explaining what I did | Pulled from the Likert response | *true in any science* | Implies that they are talking about the science community |

Table 4.6: Unclassified examples. All six comes from the open-response survey.

| **Unclassified Examples** these are exmaples of identity that did not fit into the identity components | | | | | |
|---|---|---|---|---|---|
| **Data** | | | **Analysis** | | |
| Indicators | Label | Response | 1. Connected to a practice | 2. Contains a value statement | 3. Has an explanation or justification for value statement |
| **Not an expert** - Something is not valuable because they are not experts or not physicists | Un 1 | **Q:** Communicating my results by answering specific questions is helpful **A:** Not as helpful because I am not a professional and don't necessarily understand everything that the lab had to offer, just the major concepts. | Communicating results | *Not as helpful* | *I am not a professional* |
| | Un 2 | **Q:** Having help from my group if I have questions is important **A:** I am not a professional and need a lot of help when conducting experiments so having others to lean on is helpful. | Working with a group | Pulled from Likert response | *I am not a professional* |
| **Purpose** - This is important because it shows me the purpose of this | Un 3 | **Q:** Communicating my results by answering specific questions is helpful **A:** Explaining findings is the whole purpose of doing an experiment | Communicating results | Pulled from Likert response | *whole purpose of doing an experiment* |
| **Relevance** - The practice or activity is relevant (or not) in some way | Un 4 | **Q:** Working with the equipment is valuable **A:** Is not really important because I don't do many experiments or measurements in my regular life. | Executing experiments, specifically working with the equipment | *Is not really important* | *I don't do [this] in my regular life* |
| | Un 5 | **Q:** Making connections to the bigger concepts is valuable **A:** it helps me to put forth more effort if I can understand the concept in a real life example. | Analyzing data, specifically making connections to concepts | *it helps me..* | *real life example* |
| **Utility** - Helps (or doesn't) to learn/understand/do something | Un 6 | **Q:** Using math as a tool to explain and predict is helpful **A:** As an undergraduate student, sometimes the underlying concepts behind experiments go over my head. For me, it's sometimes most useful for me to relate a concept to an equation and understand how different variables in the equation relate to one another, rather than more complicated physical variables in an experiment. | Analyzing data, specifically by using math | Pulled from Likert response | *most useful ... and understand* |

### 4.4.2 In the Data

This section highlights the places where the data connect with the model of identity. We use examples from the interviews and the open-response survey to articulate the definition of the different components within the labs context.

#### 4.4.2.1 Learning Trajectory (LT)

This work has been focused on students who are not physics majors but are STEM majors. The practices that are important in physics labs are relevant to their current or projected field. For students who do not plan on a career in physics the ability to see how physics practices may connect to their future goals is vital for them in identifying with physics. In LT 1 (Table 4.2) Blake says that he finds the practice of communicating in the course valuable because it is something he will need in his future as a teacher. A common theme in the open-response survey data is students diminishing the value of a practice because they will not need it in the future. Examples LT 2-4 all show this feature saying that the practice does not connect to their future, will not be helpful for them, and will not be something they need to know after this physics lab. It can be posited that the reason so many statements fell into this component is because the open-response data came from non-majors, who use their future goals as the concrete connection for why they might identify with some aspects of physics. It would not be surprising if this trend was not seen in physics majors, where the connection between physics and their future is more clear.

#### 4.4.2.2 Interest

An explicit interest in a community, or an aspect of that community, can be an indication of whether or not someone personally identifies with that community. In Int 1 (Table 4.3) Fern expresses that the process of communicating results and “connecting the dots” is what she enjoys about doing science, true in both her field of biology and in physics. In Int 2 and 3 the students both express a negative preference for physics, “I don’t love physics” and “I am not really into physics.” In all three cases the preference statements, whether positive or negative, are used to explain their feelings about a particular physics practice. It is not surprising that many students mentioned negative feelings and preferences toward physics, they are not physics majors for one thing, but the more the students' interests align with important physics practices the more likely the experience with the practice will positively impact their identity. Int 2 and 3 would look very different if after the mention of their disinterest in physics students described a specific interest in a physics practice.

#### 4.4.2.3 Negotiated Experience (NE)

A fundamental part of identifying with a community is the negotiation of how one fits into that community. This includes how the values and practices of the community align with or are in opposition to those that they already identify with. This negotiation can have a strong influence on how or if one comes to identify as a member of the community. This has played out in three different ways in the data. One way is through an expressed tension in the value the individual puts on something versus the community. This can be seen in NE 3 (Table 4.4), where the student describes the practice as "inconsequential" and "not the most important part." Another way NE is represented in the data is the distinction between personally valuing something and seeing the value of it. In NE 1 and 2 this is evidenced by the fact that the student recognizes the value of the practice for the course but it is not something they personally value. Along the same lines as the other two show statements that are reflective of obligation, "I only care about this because I have to." Several of the NE examples show this: NE 5 with "organization demanded by the course" and NE 1 with "important in that I need to do it." These are similar to valuing versus seeing value, where the student only cares about the practice because they are made to by the features or requirements of the course. NE statements are some of the most common in the data: it is possible that the reason for this partially falls on the fact that these students are non-physics STEM majors. As such, they have opinions about the practices valued in physics since they often have experience with similar or the same things in the courses they take in their major. When coming into their physics labs students have to address their past experiences and perspectives in negotiation with how things are done in the physics community, or at least their interpretation of that. Nearly all examples of NE statements are negative in part or whole, which is likely because these differences in practices and values pop up as internal conflicts that the students have to deal with in order to understand themselves and their identities with respect to physics.

#### 4.4.2.4 Community Membership (CM)

Part of that process of becoming a part of a community (and developing a community-specific identity) means an alignment of the practices valued by the individual and by the community. In order to feel a part of the community the individual needs to value and identify with (some of) the same practices that the community does. This can be seen as the value of the practice coming specifically from a community or a difference in value between two communities. In CM 1 (Table 4.5), they talk about the value of the practice coming from the fact that it is important in all of science. Although there are not many examples of CM in the data, it is not hard to believe that the distinctions between communities would come into focus during the process of developing a subject-specific identity. CM could even be seen as a step that follows NE: that students need to confront conflicts produced by straddling different communities before they can form their own opinions enough to evaluate different perspectives. It's possible that the students in are sample are not at a stage where they can look beyond the conflict, and as such there are very few examples of CM and many examples of NE.

#### 4.4.2.5 Unclassified

In addition to the identity statements that align with the operationalized definitions, there are also examples that do not fit into any of the pre-established bins. These are examples of identity based on the requirements for an identity statement they are focused on a practice, include a personal value statement, and are justified but that justification does not fit with the identity components. Examples of these statements are listed in Table 6. The first two examples, Un 1 and 2 (Table 4.6), can be described as references to the fact that the students are not experts and that is the reason they do not care about the specific practice. This is different than LT, where the students are projecting to their perceived future. Un 3 establishes that the practice is valuable because it is the purpose of doing experiments. This could be interpreted as a CM statement but lacks further connection to a specific community. The relevance of the practice to real life is used as justification in Un 4 and 5, which does not match up with any of the identity components. The final example is one that discusses the utility of the practice. Utility could connect to the identity model but in this example there is no connection to the future (LT), no preference (interest), there is no focus on conflict (NE), and it is not directly connected to a community (CM). Of all the identity statements, 20% were unclassified, for the reasons discussed above.

### 4.4.3 Not in the Data

#### 4.4.3.1 Recognition

Recognition was not discussed by the students in the interviews or in the open-response survey. It could be predicted where statements of recognition might show up, recognition as a member of the community from peers or instructors. Grades could be perceived as a form of recognition. Although attempts were made in the interviews to probe for connections to recognition, it did not come out. In the interviews for example, there were only examples of personal recognition, "I was able to explain this to someone else, so I must really understand it." One reason this might not have come up in the data is that recognition is not closely tied with practices and related experiences, therefore the focus on practices artificially suppressed examples of recognition. It could also be that in these lab courses recognition from peers is not of the greatest importance to the students. The courses where the majority of the student data comes from do not have any special emphasis on recognition either by instructors or peers, while they do explicitly focus on physics practices and the values of them (Ch 3). A last possibility is that impactful recognition comes not from large enrollment courses but instead through departmental or cohort interactions. Since these interactions were not addressed in interviews or the open-response survey they are not detected in the data.

#### 4.4.3.2 Competence

Competence is the belief in one's ability to perform specific practices relevant to the community. It is not hard to establish a direct connection between a person's competence in a specific practice and its impact on their identity. Therefore, it was surprising that statements of competence in relation to identity were not detected in the data. Competence was directly probed in some of the interviews by asking if the students felt that they achieved their goals in levels of understanding or skill with respect to a specific practice. Even with that direct line of questioning no examples of identity related competence were found. Although it is possible to predict potential statements, "this practice is important for physics but I am not good at it so..." it did not come up in the process of this work.

#### 4.4.3.3 Not Combined

One of the goals of this work was to adapt a specific identity framework to a different context. The components of the framework were each a combination of two perspectives on identity, COP and the work done by Hazari et al. [4, 19]. Of the examples found in interviews and the open-response survey, none of them reflected the combination. During the initial coding of the statements, there was no evidence of the framework components being combined as they are in the Close framework. First of all, competence and recognition were combined with community membership and negotiated experience respectively and no instances of competence or recognition were detected in the data at all. Although it is possible to see how they could work as combined components in this context. Community membership and competence for example, a student's identity could be impacted by whether or not they are competent in the skills and practices valued in the labs community. Even examples of recognition combined with community membership and competence are possible, the student's competence in the valued practices is recognized by their peers or instructor. An additional interpretation that combines recognition with negotiated experience is that the student needs to figure out how recognition is utilized and given in this community just as they have to figure out the practices of the community and integrate them with their other community-specific identities. In the Close et al. framework, interest was combined with learning trajectory and although there is evidence of both components there is not evidence of them in combination with each other. An hypothesized example of this could be an adjustment to LT 1, where it becomes "...makes science enjoyable to me and is why I will make science my career." None of these proposed examples were evident in the data. These outcomes lead to the separation of the identity components as compared to Close et al.. The statements were coded from there and another researcher was included to validate the coding of the identity statements.

### 4.4.4 Summary

In the analysis of both the interviews and the open-response survey the combined framework [21] could not be applied. There was no evidence of any of the components being combined and when broken into six distinct components evidence was found for only four of them (Fig. 4.3). Table 4.7 shows counts of the numbers of statements from the open-response survey that were coded into each specific identity bin.

Table 4.7: The number of statements from students coded into each of the identity components.

| Component | Statements |
|---|---|
| LT | 38 |
| Interest | 19 |
| NE | 42 |
| CM | 15 |
| Unclassified | 24 |

## 4.5 Discussion

This paper has described the work done to characterize identity development in physics classes, with a focus on lab practices. This was done in alignment with the operationalized model from Close et al. [21]. Multiple examples from the literature, interviews, and an open-response survey were provided as justification for connecting labs to affective measures and lab practices to identity development. These examples will be briefly summarized and discussed in this section.

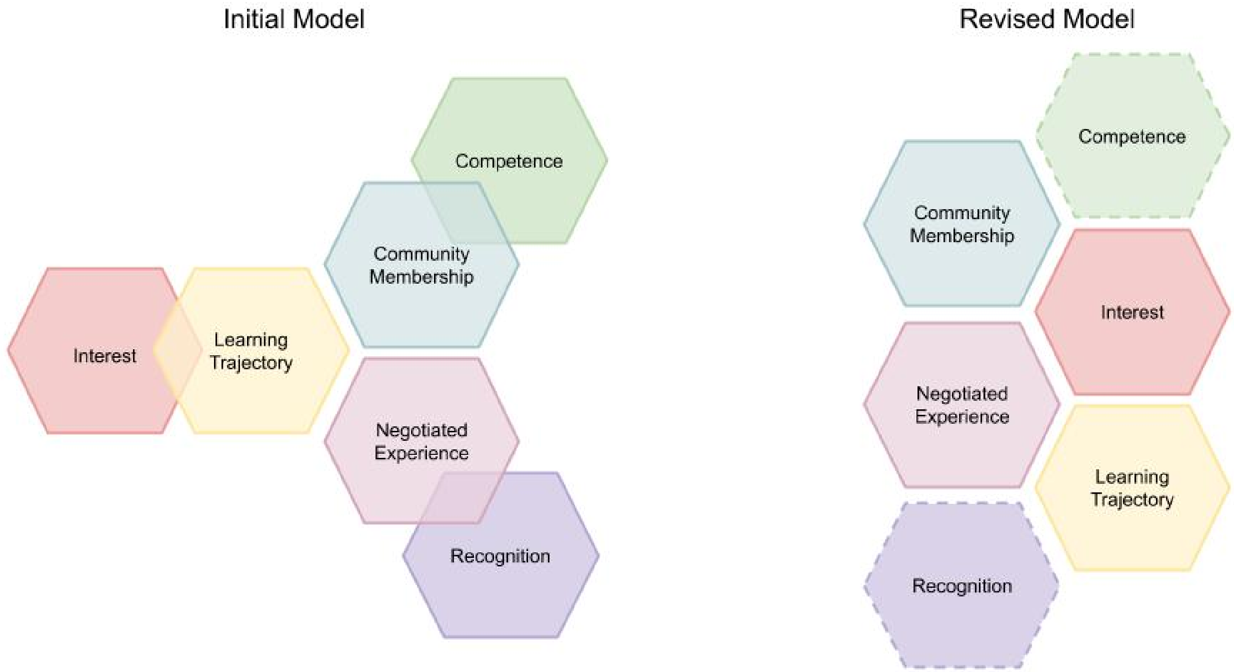



Figure 4.3: A visualization of the initial model of identity from Close et al. 2016 and the revised model based on the data and analysis presented here. The overlap in the intial model is meant to illustrate the combination of components.

### 4.5.1 Labs and Affect

Both the literature on labs [17, 15, 82, 16] and on physics identity [21, 54, 53, 56] show clear connections between engagement with practices and changes to attitudes and other affective measures. Similar impacts of practices can be seen in statements LT 1 and Int 1, where both express positive views of two physics practices. Even Ex 2, which is not an identity statement based on the criteria, still shows the positive attitudinal impact lab practices can have with Adam talking about the "sense of accomplishment." These results connecting practices to attitudes and affect also come with limitations, for one, not all lab courses center authentic skills and practices. Those that do still require that the practices are implemented authentically and valued within the context of the course, as evidenced in grading and learning goals (Ch 3). Large scale changes can also depend on whether or not positive affect and attitude were goals of the course design and implementation. Even with these limitations, the connection between authentic engagement in physics practices and positive attitudinal and affective changes, including physics identity, should provide significant evidence for the value of these experiences for our students. The skills and practices of physics are relevant to all science students, physics and non-physics majors alike. In many physics departments, the majority of students served are non-physics STEM majors, so it should be ensured that the courses serving the majority of the students going through our departments are effective in the goals relevant to these students.

### 4.5.2 Practices and Identity

Wenger [4], Irving [53, 54, 56] and Close [21] all indicate the connections between identity development and the valued practices within a specific community. This connection is additionally evident in all of the examples of identity statements discussed in this paper, every example provided highlights this connection. Though this again comes with limitations, this work was done with a communities of practice perspective and community of interest has been tentatively defined as the labs class community as a proxy for the larger physics community. This requires that the students see their lab courses as an authentic stand-in for the physics community, Int 3 and 4 show evidence that they do. Either way, if identity development, and the benefits connected to that, are goals in the course instruction than that implies that it is necessary to ensure that there are opportunities for students to authentically engage in physics practices in order to aid in the development of their physics identities. This paper has described the effort to understand identity development in lab classes in connection with physics practices and as part of that the work to operationalize the framework used in Close [21] in the context of laboratory practices. In that framework the components were combined from two different perspectives on identity [4, 19]. This combination of components was not reflected in our data from practice-focused lab environments, instead evidence was found for four of the six individual components. Learning Trajectory highlighted the ways in which students interpret the relevance and value of specific practices based on their projected future plans. Interest showed statements of positive or negative preferences to different lab practices, or aspects of practices. Negotiated Experience covered the multitude of ways students must adjust and adapt to the values, expectations, and practices of one community as compared to the other communities they are members of. Community Membership provided examples where the specific value a student has for a practice originates from their membership in a specific community. There was no evidence of either competence or recognition, although it is possible to predict how they could fit into the context of physics labs. Recognition could have been represented in relation to the grades received, or as recognition as a member of the community from peers or instructors. It is easy to see how competence could fit with a focus on practices, whether or not the student is competent in specific physics practices could impact their identity. Although we found no evidence of the components being combined we again can predict what that may have looked like. Learning trajectory and interest could be represented as a positive preference for a practice that aligns with a projected future path. Negotiated experience and recognition could highlight the social aspects of adapting to a new community and the recognition from peers as an equal member in that process. Community membership and competence might be examples of the student's perceived competence in practices that are valued in the physics or lab community. It is possible to hypothesize what these may look like in this context but again, with the analysis of the described data sources, no evidence was found. The analysis has shown that it is possible to use communities of practice to study identity development in lab classes but not in the combined way that Close does. This requires the assumption that lab classes represent a COP, as argued in Irving (2014) [57]. The students also need to see the connection between their course and the larger physics community (Int 3 and 4). It has been found that COP fits the student responses to both interview questions and to the open-response survey. The open-response survey only went to intro non-physics STEM majors, which suggests that this application of COP to identity development is confirmed for these students specifically. From this though, it can also be extrapolated that the same can be said for intro and advanced physics majors, although evidence for this is not provided here, it will be highlighted in an upcoming publication. Although COP fits the context, the same combination of components that Close [21] describes does not appear to, as there is no evidence of any of the six components as combined with each other in either the interviews or open-response survey results. This may be tied to the population, students within a lab course versus ULAs teaching other students. It is possible that the process of identity development of the ULAs, who have a unique relationship to physics and the physics community, is more complex than that of our students and therefore results in these intertwined components. Building on the difference between students and ULAs, the context of a classroom community, for the students, and the multilayered ULA and physics teaching communities for the ULAs may also be responsible for the evidence (or lack) of combined components. We do not believe Close was wrong to combine the components, as evidenced by the results of their work, but our study implies that the combined components are not necessarily broadly applicable. More work with this framework on identity, either in a fully qualitative or in a mixed methods approach such as this, may show something entirely different. Either way, at this stage it should not be assumed that this framework would apply to any context without preliminary work and potential adjustments.

# CHAPTER 5

# WHAT COUNTS IN LABORATORIES: TOWARD A PRACTICE-BASED IDENTITY SURVEY

The following chapter was published in the proceedings of the 2018 Physics Education Research Conference [88] with minor modifications from its appearance in publication. It was published with co-authors Marcos D. Caballero, Paul W. Irving, and Vashti Sawtelle.

Some content in this chapter may be repeated in Chapter 6 in order to ensure the full survey development story is told in Chapter 6.

## 5.1 Introduction

Laboratory courses in the undergraduate physics curriculum are intended to provide students with opportunities to participate in authentic physics practices. There have been national calls to develop courses that emphasize physics practices and focus on how science is done [61, 12, 5]. The American Association of Physics Teachers (AAPT) Committee on Laboratories released lab guidelines, with focus areas that highlight the skills and practices necessary in doing physics [5].

The emphasis on practices in these lab courses makes them an ideal place to investigate the impact the practices are having on our students. The opportunity to engage with authentic physics practices is an essential step in the development of a physics identity [3]. We are working to develop a survey to measure students' physics identity in lab courses with a focus on the effect of lab practices. Identity is a construct that is nuanced in qualitative studies, so a survey designed to probe identity must be tightly connected to a theoretical framework. In this paper we show how we build on existing survey design methods by staying close to student understanding of physics practices and add an intentional focus on the identity framework in every step in our survey design. We show how asking students to reflect on scientific practices and values are critical steps in designing a survey on practice-based identity.

## 5.2 Theoretical Background

**Identity:** Identity is a multidimensional construct that describes how an individual sees themselves and how they situate themselves with respect to a specific community. We are adapting the identity framework presented in [3], which draws from Communities of Practice (CoP) [4] and [19] frameworks. The framework has three main components: community membership & competence (CMC), learning trajectory & interest (LTI), and negotiated experience & recognition (NER) (Fig. 5.1). Due to limits in space we will break down these components further in future publications. For the purposes of this paper we are adapting these components to our context with the knowledge that they may not be what best describes identity in physics labs.

The context of physics labs and our goals of staying close to the theory and to the students' ideas align to pull the majority of our focus onto the specific lab practices, how students interpret them and how they identify with respect to those practices. This means examining the overlap of the experimental physics community with the other communities the students are a part of, and specifically, understanding how they interpret physics practices through the lens of those communities.

Our study of identity is further complicated by the fact that we are working to produce a survey that can be distributed on a large scale with closed response questions that combine to tell us about the participant's physics identity. This has meant that we have a carefully operationalized definition for what we count as an identity statement. We are looking for three main components of an identity statement: *the student addresses the practice, applies a value statement to it, and then connects it back to one of the identity components in* Fig. 5.1. The definition here relies on the student's interpretation of the physics practice and a personal value statement about the practice in order to meet the first two criteria. The third component helps us to maintain our ties to the theory. We recognize that this process of operationalizing a complicated construct into a single sentence loses much of the nuance. Below, we argue that the intentional and focused process we are going through to develop question statements respects the complexity of identity as a construct.

**Physics Lab Practices:** The CoP framework on identity defines a CoP based upon the shared

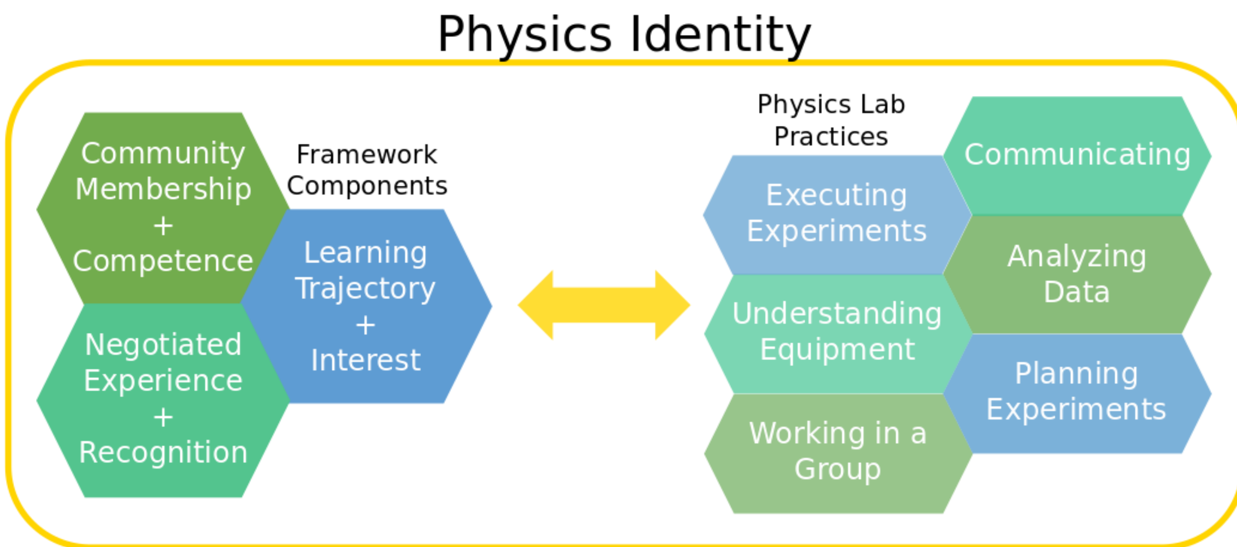



Figure 5.1: The components of our theoretical framework, with the interaction between the physics lab practices and the components of the identity framework forming the physics identity [3, 4, 5].

practices, skills, and ideas within a specific community [4]. Physics lab practices are the skills and activities valued and utilized within the experimental physics community. We focus our initial survey design on practices from the AAPT lab guidelines and those emphasized in the physics lab courses at our institution. These initial practices were adapted based on responses in the student interviews, which are described in Sec. 5.3.1. We have thought carefully about how to represent the practices in a way that they might resonate with even if they are not intending to become physicists.

The final six broad lab practices on which we focus include: analyzing data, communicating, working in a group, understanding equipment, designing experiments, and executing experiments (Fig. 5.1). Starting with broader definitions we have iterated on this list based on student interviews where we took in their interpretations. We acknowledge that our list of practices is limited and may not be consistent across institutions, for example our lab courses do not currently emphasize computation, while other institutions do [89]. We hope to expand our data collection to additional institutions in order to account for this. In this paper we also do not discuss the centrality of particular practices as the CoP framework would call for, though we have structured our data collection to allow for this analysis in the future.

## 5.3 Survey Development

We have been keeping the interpretations of the students and the components of the theoretical framework at the center of our entire survey design process (as laid out in Fig. 5.2). In the interviews, we worked to flesh out their understandings of the lab practices that are valued in the physics community and to evaluate the ways they identify with those practices. The creation of the survey has also centered on the idea that though students may identify with physics many of them would not now, or maybe ever, identify themselves as physicists. This fact means that we need to carefully consider the intersection of students' communities with the physics community embodied in the laboratory classroom. Therefore, in initial iterations of this survey we take into account the many communities that these students are members of: their major, the science community, sports/teams, racial/ethnicity groups etc. We acknowledge that students from life sciences are not necessarily going to see physics practices the same way that a graduating physics major might, but we assert that they both identify with physics in some way. To account for different interpretations and for future exploration of the centrality of these different practices for students we have collected data from introductory to upper division labs.

### 5.3.1 Interviews

Traditionally surveys are designed around "expert" ideas, but our students are not yet experts [90, 74]. To make sure that our questions are representative of their ideas we need to understand all the ways students are interpreting the practices. For example, one student's interpretation of "analyzing data" might differ significantly from another's, which means we have to be specific about the language and interpretations we are using in the survey design. To design a survey to be applicable across a variety of students, we conducted semi-structured interviews with nine students from an introductory algebra-based physics lab for non-majors and six students in upper-division physics labs.

In the interviews we asked participants to define each of the lab practices and to describe what

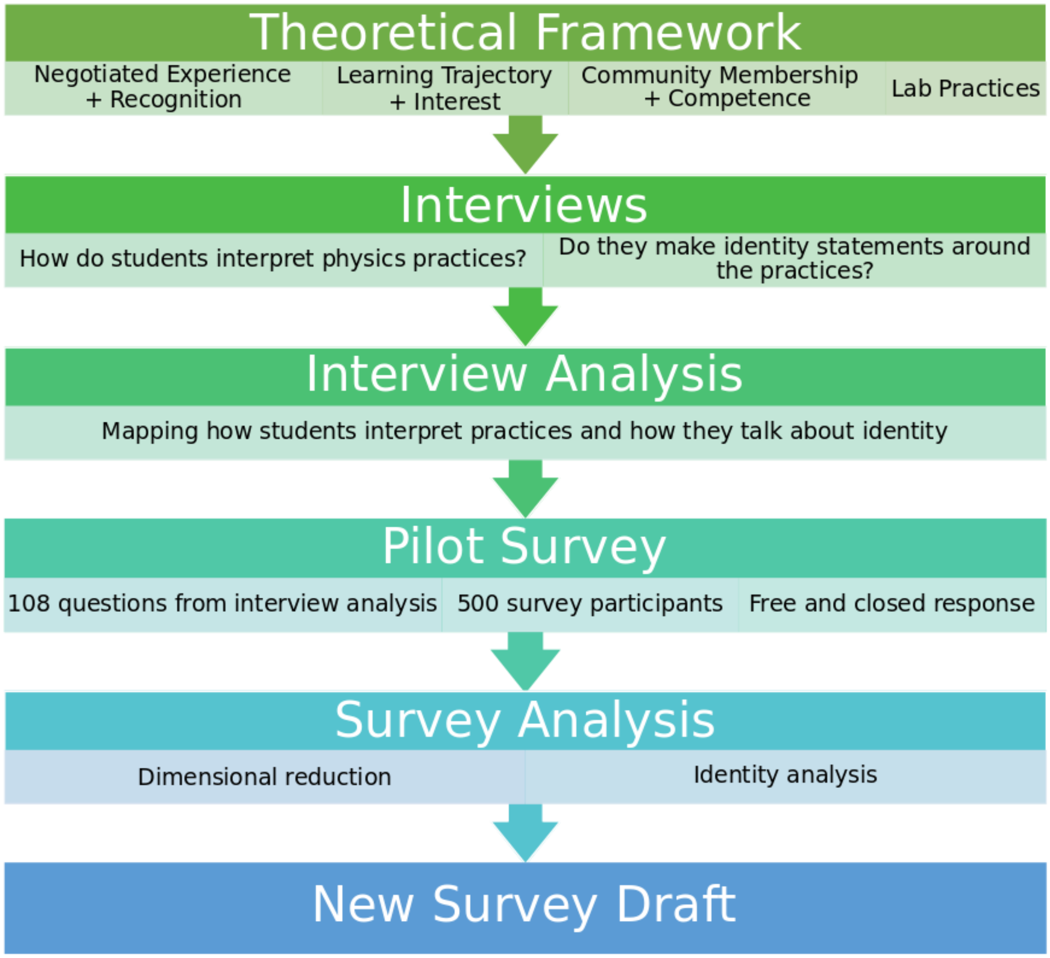



Figure 5.2: The survey development process. The theoretical framework as described in Sec. II.

the practices looked like in their physics lab course (e.g., *"What does data analysis mean in your lab class?"*). Then they were asked whether or not they found that practice valuable (e.g., *"Do you find that useful?"*). This enabled us to first, explore a variety of interpretations of specific practices and second, to explore how students may (or may not) identify with that practice.

We used the interviews to map the breadth of students' interpretations of the practices, not to make claims about how specific students understand the practices. The analysis focused on covering all interpretations and levels of centrality in the students' statements. Within each practice we found interpretations fell into specific themes, which we refer to as sub-bins (Fig. 5.3). From those sub-bins, we identified different types of student responses with different levels of centrality – the spectrum of responses. We then turned those responses into question stems for the pilot

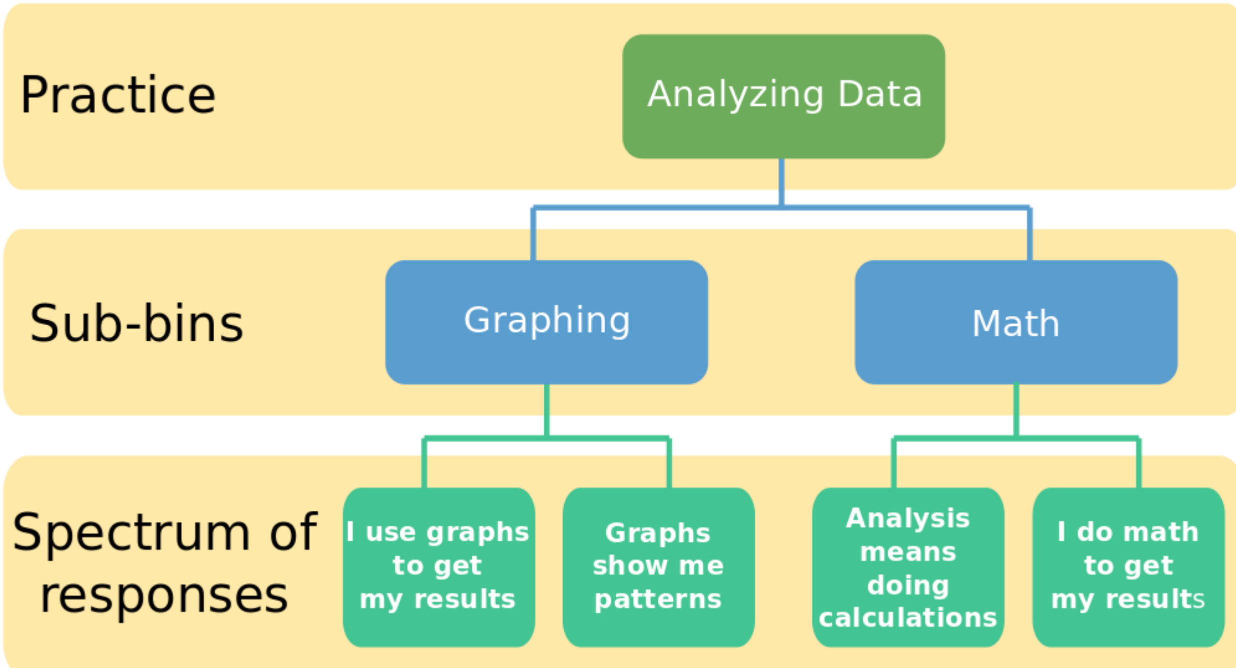



Figure 5.3: This is an example of the interview analysis process for the practice of analyzing data.

survey. For example, from the interview question: *What does data analysis look like in your lab?*, we looked at student responses that fell into a similar theme, graphing in this case.

> As soon as you have the graph and data in front of you, with a certain mindset, [you] can interpret what it actually means. (Dean, pseudonym)

> So interpreting the results, in this class, we use graphs and stuff to do that. (Fern)

Looking across responses that fell into similar categories, we wrote pilot question statements that would represent student interpretations of the practices that they could endorse in closed response questions. For example, the above student quotes combine into the question stem for the pilot survey: *In my lab, using graphs to interpret results is important.* An overview of the practice space and the pilot survey questions produced can be seen in Table. 5.1.

In the analysis we also evaluated the ways students described how they identified with specific practices. This lead us to our definition of an identity statement as discussed in Sec. 5.2. To

Table 5.1: Overview of Practice Space.

| **Practice** | **Sub-bins** | **Pilot Survey Questions** |
|---|---|---|
| Analyzing Data | 7 | 19 |
| Communicating | 3 | 18 |
| Working in a Group | 9 | 25 |
| Understanding Equipment | 7 | 25 |
| Planning Experiments | 3 | 14 |
| Executing Experiments | 2 | 7 |
| **Total** | 31 | 108 |

highlight the steps we went through to form our definition we compare two statements where students identify with lab practices.

> Blake(discussing uncertainty): I do understand its importance, and see it as a necessary thing. It's just, I personally will never really need to take uncertainty as seriously as it is taken in these upper level lab classes and...I don't look at it the same way as someone who's thinking 'I want to do experimental physics for the rest of my life'.

We see that Blake refers to a specific practice, uncertainty in analyzing data (which he defines earlier in the interview). He makes a *personal* value statement about it: *I do understand its importance, and see it as a necessary thing*. He then connects it back to the identity framework: *I personally will never really need to take uncertainty as seriously.* We see this statement fitting into the LTI component of the identity framework (Fig. 5.1) because Blake is projecting forward to his future career (as a high school physics or math teacher), where he does not think he will need to use uncertainty. These components of Blake's statement address our main goals in the survey development process, covering his interpretation of the practice, the way he does (or does not) identify with it, and then connecting it back to our theoretical framework. We contrast this example with one that does not make the connection back to the theory.

> Beth (describing something she found exciting): It was good to, plug it all into the calculator and [see] this is a reasonable answer. So, getting something that...could be

> right and doing that without a procedure is more self-satisfying because...you relied more on yourself.

Beth, too, refers to a practice, broadly analyzing data, and she applies a value statement to it: *more self-satisfying because...you relied more on yourself.* But, she does not make the value statement in a way that easily connects to the framework to mark it as an identity statement. If she had talked about how important self-reliance is either for her future (LTI) or as an important part of a community she is a part of (CMC), then we could classify it as an identity statement. This comparison between statements from Blake and Beth exemplifies how we came to include the third requirement to our identity statement definition, the students' statement connects back to an identity component in (Fig. 5.1).

The analysis of the interview data supported covering the breadth of students' interpretations of the six lab practices (Table 5.1). Working from this analysis, we built questions for the pilot survey that explicitly asked students to reflect on the practice and the value statement, but left open how participants' statements connect the practice back to the identity framework.

### 5.3.2 Pilot Survey

The purpose of the pilot survey was not statistical validation that is traditionally part of a survey development process, we were not yet at a point where such validation would be necessary or useful. The overarching goal instead was to cover the ways that students identify with the physics practices, similarly to how the interviews were used to determine how students were interpreting the practices. This connects well with our intentions in the design process, we want to be certain of our students' ideas and interpretations, and we need more information to create questions to probe identity reliably. In addition to the identity information we are using the pilot survey to confirm full coverage of the practice space.

We worked to elicit identity statements that met our criteria and we primed participants to think about specific communities throughout the survey. We built the first two components of the criteria directly into the prompt, addressing a practice and applying a value statement to it. We then broke

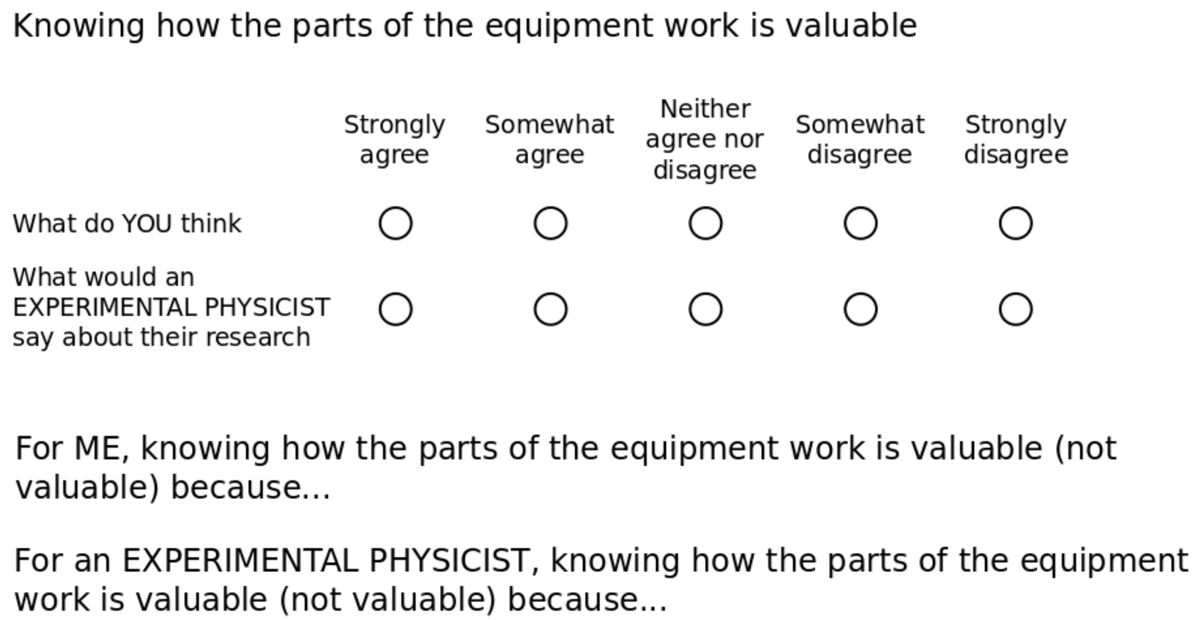



Figure 5.4: An example question from the pilot survey.

each question statement into four pieces. The first two were Likert-scale closed response items, which gave the participants space to endorse (or not) the value statements. The other two were free response questions where participants were asked to explain their reasoning, the aim being that they would make that final connection to the identity framework.

In each question group we asked the participants for both their own perspective and what they thought an experimental physicist might say (see Fig. 5.4 for an example), following the strategy from the Colorado Learning About Science Survey in Experimental Physics (ECLASS) [91]. We did this as a way to prime them to think about specific communities when answering questions, in addition to asking about the communities they fell into at the beginning and end of the survey. We also found that in preliminary trials participants supplied the more "expert" response before the more personal one, so this provided them space to do both in a transparent way.

To ensure that our survey development process remained aligned with student ideas we needed to retain the level of variation in their interpretations of the practices. We structured the pilot survey to target this alignment by first, maintaining our large sample of question statements from the interview analysis. We also needed large numbers in responses to justify removing redundant questions and to confirm that our interviews were representative of a much larger sample. This was accomplished by distributing the survey to the students in the introductory algebra-based lab for non-majors at the end of the spring semester, roughly 650 students. With nearly 500 responses to the survey we received between 40-60 individual responses to each of the 108 questions.

## 5.4 Discussion

This paper has described the process we have taken in developing a practice based identity survey, with our ideas about identity and practices grounded in the literature [3, 4, 5]. We described our process of using interviews to map the breadth of students' interpretations of the practices. From that, we produced 108 questions for an atypical pilot survey, where we work to validate the interpretations of practices and elicit identity statements.

We argue that in order to produce a robust survey that measures our intended construct it is essential to make sure each component of the survey development process is focusing on the students, derived from the information we get from them and is closely tied to the theoretical framework on identity. In doing so we intend to produce a survey that will tell us about our students' physics identities and the practices we emphasize in our lab courses. We also aim to progress in our understanding of physics identity, especially for students who would not necessarily call themselves physicists or those who do not intend to go into a physics related field at all. We posit that a process like ours is necessary to ensure a survey speaks to and for the community we are studying, students in physics lab courses in our case. Especially, when studying something as nuanced as identity, we need to be intentional every step of the way to understand our students, to ensure that they understand us, and to retain the theory as the foundation.

**CHAPTER 6**

**SURVEY DEVELOPMENT**

## 6.1 Introduction

The overall direction of this thesis work has been to produce a survey that measures identity in lab classes. This chapter will lay out the entire survey development process, as seen in Fig. 6.1, up to the current stage. Anything discussed in previous chapters will only be briefly mentioned here. This chapter will describe the different iterations of the survey from the initial interviews to the three different versions of the survey and related analysis. This chapter concludes with the current state of the survey, which is made up of 24 closed-response practice questions and five identity questions.

The theoretical framework being utilized to model identity was described in both the Literature Review and Identity Chapters (CH 2 & 4) and will not be repeated here. In addition to a model for understanding identity in the lab classes, the relevant practices and student understanding of these practices needed to be determined. A combination of the AAPT lab guidelines and the learning goals for the transformed introductory lab course (see Chapter 3) lead to the six practices


Figure 6.1: The survey development process from establishing the theoretical framework to describe identity development to the newest version of the survey.

that this work focuses on communicating, analyzing data, executing experiments, working in a group, planning experiments, and understanding equipment. After the framework for practices and identity was established, interviews were conducted with students enrolled in a variety of physics lab courses at Michigan State University (the second stage of the development process in Fig. 6.1). Fifteen students were interviewed, six upper-division physics majors (or minors), four from the transformed introductory labs [40], and five from the untransformed introductory labs. The goals of the interviews were to determine how students interpret specific physics lab practices and to characterize the kinds of identity statements they make around those practices. The interviews were semi-structured, the students were asked to describe what the practice in question meant to them, and then they were asked about whether or not they found the practice valuable (See Appendix C for interview protocol).

## 6.2 Interview Analysis

### 6.2.1 Practice Space

We were trying to fully map the space of students' interpretations of physics lab practices. The interviews were coded for the different practices of interest. Quotes and summaries were pulled for each practice. Emergent coding was then done to get a picture of the main ways students talked about the practices and produce sub-bins describing the central interpretations. All of the example statements were coded into the sub-bins and then summarized into a few representative statements describing the specific aspect of the practice. A visual representation of this process is in Fig. 6.2 below, and Fig. 6.3 shows specific examples (see Appendix E for full examples).

For example, from the interview question: "What does data analysis look like in your lab," we looked at student responses that fell into a similar theme, graphing in this case. Dean: "As soon as you have the graph and data in front of you, with a certain mindset, [you] can interpret what it actually means." Fern: "So interpreting the results, in this class, we use graphs and stuff to do that." These quotes from Fern and Dean lead to the representative statement, "In my lab, using graphs to interpret results is important." (Fig. 6.3 also provides examples of this)

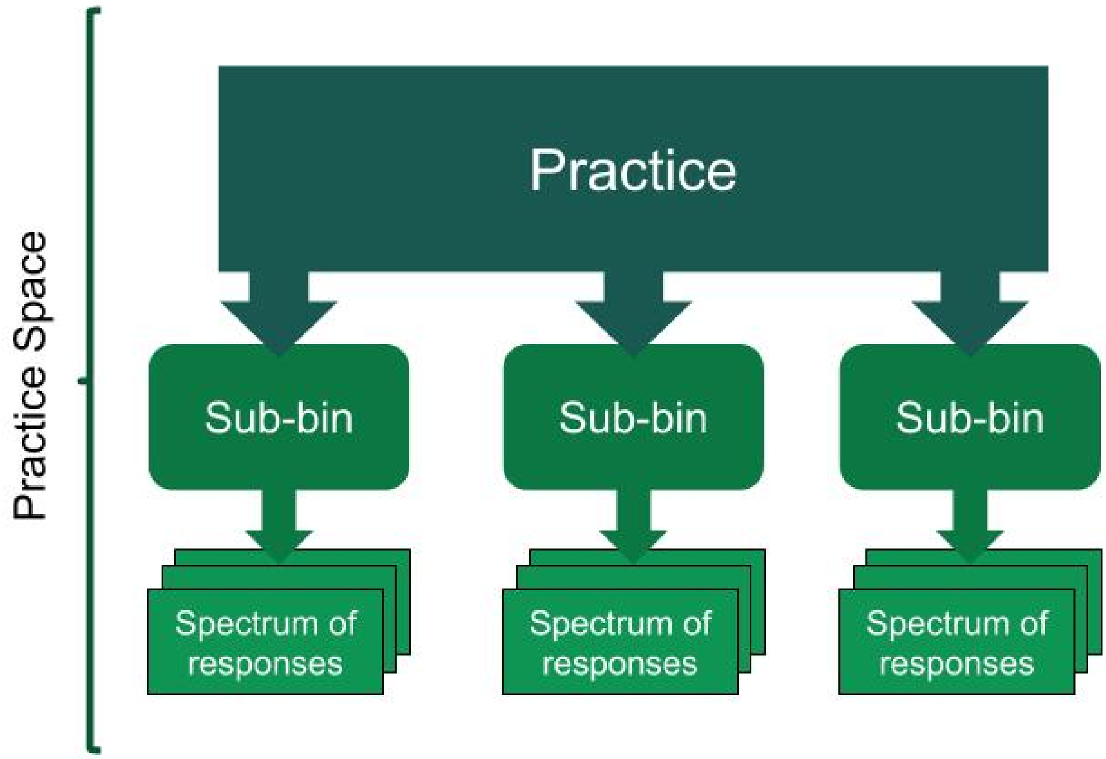



Figure 6.2: Visual representation of the ‘practice space’

This process was completed for all of the practices and all of the interviews, resulting in 108 practice questions to be used in an open-response survey. A table summarizing the number of sub-bins and survey questions produced from the analysis is shown in Table 6.1. Fewer sub-bins just means that there were only a few ways that students were found to interpret the practice.

Table 6.1: Summary of the outcome of the interview analysis, showing the number of sub-bins and questions for each practice.

| Physics Lab Practices | Sub-bins | Survey Questions |
|---|---|---|
| Analyzing Data | 7 | 19 |
| Communicating | 3 | 18 |
| Working in a Group | 9 | 25 |
| Understainding Equipment | 7 | 25 |
| Planning Experiments | 3 | 14 |
| Executing Experiments | 2 | 7 |
| Total | 31 | 108 |

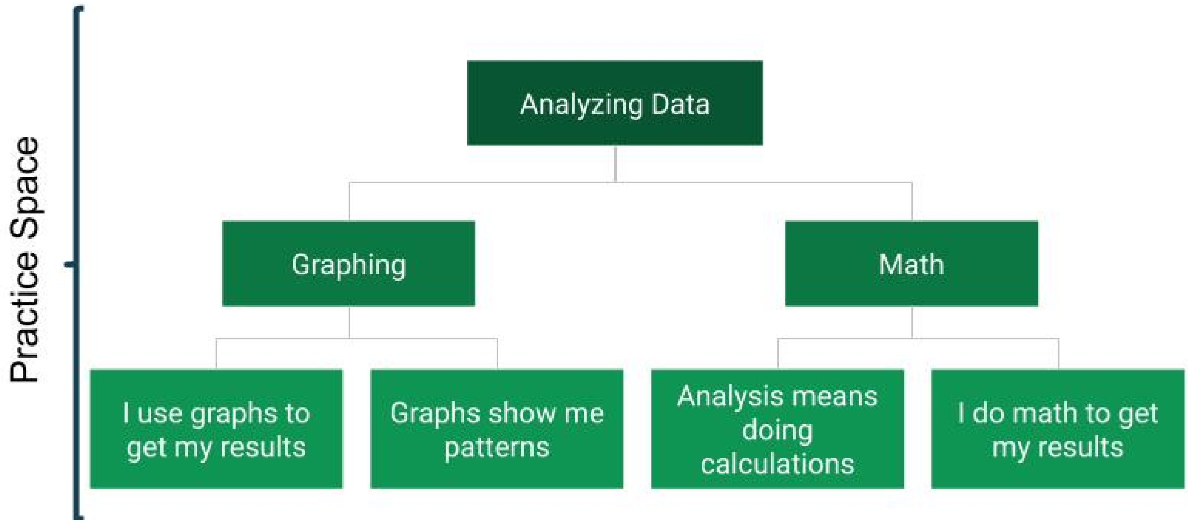



Figure 6.3: A subset of the practice space for analyzing data shown with specific examples.

### 6.2.2 Identity

There was not enough information from the interview analysis to create identity questions to mirror the practice questions, or to determine if the identity model fit our data and context (See Chapter 4 for further information). The identity statement criteria, described in the Identity Chapter, was used to develop open-response questions used in the first version of the survey.

### 6.2.3 Survey Development Overview

In the development of a closed-response survey, especially one that can be studied analytically, it is essential to reduce it to a reasonable size, reasonable meaning that a student can be expected to answer all of the questions in a moderate amount of time. The first version of the survey had 108 questions, which is clearly not reasonable, so along with confirming that the practices interpretations were representative, and developing closed-response identity-specific questions, a goal of the analysis of this version was to cut down the number of questions in the survey dramatically. Figure 6.4 outlines how this was done at each step. The methods used to eliminate questions are briefly described in this section, and the specific decisions are detailed in the rest of the chapter.

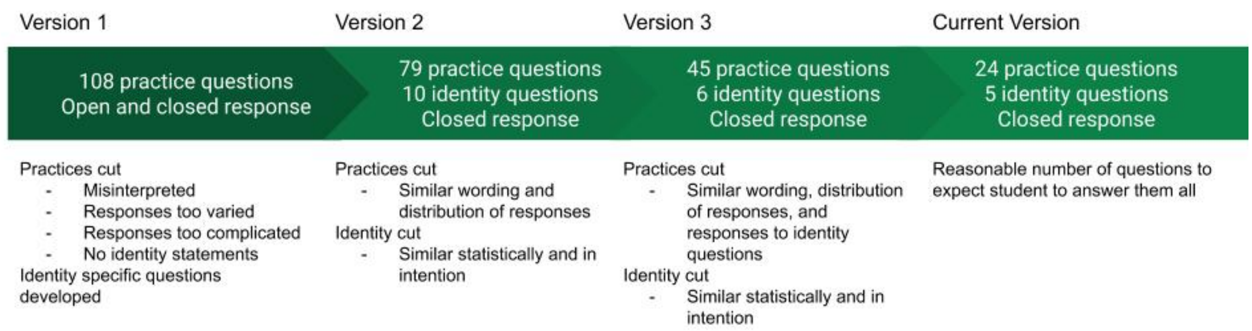


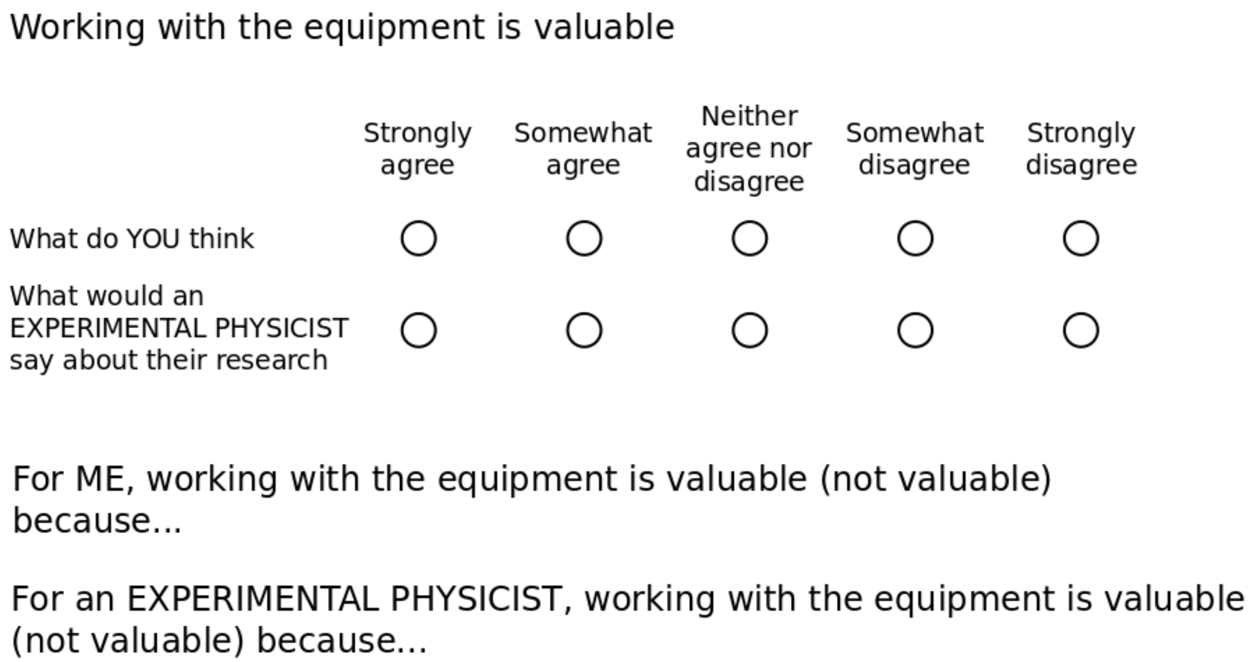

Figure 6.4: Overview of the different versions of the survey, described in detail in the following sections.

### 6.2.4 Similar Distributions of Responses

In order to justify the inclusion of an item in a survey, it needs provides unique information. There is value in confirmatory information (i.e., a few questions here and there that cover the same thing) but we take that into account with groups of questions asking about the same practice. If multiple items are asking about the same thing, in the same way, the repeated items are providing no new information. All versions of the survey after Version 1 were analyzed for redundancy in practice questions. To do this initially, when the number of responses did not allow for robust statistical analysis, items were considered for collapse or removal if they seemed to be asking the same or a similar question and if the distributions of responses were visibly, if not statistically, similar. In Version 3 we had the number of responses to each item necessary to perform statistics to determine if the distributions were similar. We did $\chi^2$ pairwise tests on items within each practice group, the details of this analysis can be found in Appendix F. The methods used to reduce or add questions at each stage are illustrated in Fig. 6.4 and detailed in the rest of this chapter.

## 6.3 Version 1 - Open-Response Survey

There were two primary goals for the open-response version of the survey. Concerning practices, the goal was to confirm we have covered the whole of the practice space (Fig. 6.2) and reduce the number of questions. For identity, it was to generate more examples of identity statements in order to understand identity in our context, as part of adapting Close's model [21], and to produce questions


Working with the equipment is valuable

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | ○ | ○ | ○ | ○ | ○ |
| What would an EXPERIMENTAL PHYSICIST say about their research | ○ | ○ | ○ | ○ | ○ |

For ME, working with the equipment is valuable (not valuable) because...

For an EXPERIMENTAL PHYSICIST, working with the equipment is valuable (not valuable) because...

Figure 6.5: Example item from version 1 of the survey (Ref. DA5).

that reflect identity for a closed-response survey. Each item for the open-response survey had four parts, two closed- and two open-response. The closed-response questions were Likert scale with the same structure 'This practice is important...' they then have two responses to this 'For ME' and 'For an EXPERIMENTAL PHYSICIST.' We asked for both of these, like the ECLASS [1], because during beta tests of the survey the participants were uncertain if they should answer based on their own thinking or based on the 'correct' answer. The other two parts were open-response, where they could explain their reasoning for how they answered the two Likert questions. A complete example is shown in Fig. 6.5 (see Appendix H for the full survey).

The open-response survey was distributed via Qualtrics[1] at the end of the spring semester 2018, to a transformed introductory algebra-based physics lab for non-physics majors [40], a total of 650 students. Responses from approximately 500 students were collected. Each student received a randomly selected ten of the 108 practice questions, in the format shown and described above. As compensation for completing the survey, the students were given a small amount of extra credit added to their in-class participation scores.

[1] Qualtrics, 2019, Qualtrics Labs, Inc. Provo, UT, USA

### 6.3.1 Version 1 Analysis

#### 6.3.1.1 Reduction of Practices

At this stage, the goal was to reduce the number of practice items. Questions were removed for several reasons, if they were being misinterpreted by students in the open-responses, the question statement was confusing based on the open-responses or others (e.g., many responses that were 'yes and no' so they would not translate well to a fully closed-response version), or they had no examples of identity statements in the responses. Several examples of items from the practice 'group work' that were removed are listed in Table 6.2 below, along with the reason for their removal. The analysis of Version 1 of the survey brought us from the initial 108 practice questions down to 79.

Table 6.2: Group Work questions that were removed at this stage and the reason for removal.

| Question Statement | Removed | Reason for Removal |
|---|---|---|
| Being accountable to my group (GW2) | Yes | No identity statements in the responses |
| Talking things out with my group (GW8) | Yes | Many of the responses contained a structure of 'both yes and no' |
| Figuring out how to work with my group (GW4) | Yes | Responses showed that students were ignoring 'figuring out' in the question |

#### 6.3.1.2 Developing Identity Items

The identity analysis took on a different direction; the goal was to characterize the types of responses and turn them into questions for a closed-response survey. The open coding and analysis are discussed in Chapter 4 and will not be repeated here. As described in Chapter 4, the majority of the identity statements fell into two components, Learning Trajectory (LT), and Negotiated Experience (NE). We decided to focus on just those two components moving forward. In order to produce identity questions to be used in a closed-response survey, we needed to break down and characterize the different student responses. The first step was to break down the responses into the specific parts that made them identity statements.

An example survey question and response: *Q: Being able to communicate my understanding is important. A: Being able to communicate my understanding would be very important when working with many patients a day to help explain their progress.* In this response, the essential parts (for being an identity statement) are 'would be very important' and 'when working with [...] patients.' This is an example of an LT response.

An example of a survey question and a response that fits into NE: *Q: Interpreting graphs to understand relationships between parameters is important. A: Not important because I don't like graphs, and I feel obligated to make one even when I don't understand the concepts very well.* Here the central parts are 'I don't like graphs,' 'obligated,' and 'didn't understand concepts.'

For the components, LT and NE, we did this with every response to the open-ended survey ($N$ = 80) and sorted the various ways of saying the same thing in order to produce statements for the survey that matched the typical structures and meaning.

**Learning Trajectory:** From the analysis, LT statements primarily fall into two categories, future and after. Future is any reference to the future concerning plans/goals/careers. As our sample contains a lot of pre-medical school students, we also found that statements about future 'patients' appeared in this category. The other category is after, that is where they do not specify a timeline or specific goal but instead say 'I do (not) need [this practice] after this class.' The LT statements were sorted into four bins, three of those are future-focused, and one is after. The next step was to look for distinct features of the statements in each category. The responses that fell into the patients-future category were all positive and included phrases like 'I will use this' or 'this is something I would need.' Career-future responses were mostly negative, 'I will not need this for my career.' Future-future responses, those that use the word 'future' but do not specify things further, were a mix of positive and negative. Although it seems like the after statements should fall into the future category, the structure and types of sentences that fit in that component were different from those that fell into one of the three future categories. All of the after responses were negative. Representative examples for all types of responses are in Table 6.3.

Four representative examples, one for each of the four categories, were pulled from those in

Table 6.3: Summary of the outcome of the interview analysis, showing the number of sub-bins and questions for each practice.

| Learning Trajectory - LT | | |
|---|---|---|
| Components | Category | Examples |
| **Future** | Patient | This is something I will need when working with patients in the future |
| | | This would be important when working with patients |
| | Career | This is irrelevant to my future career |
| | | I won't need to know this for my career |
| | | This is something I will use in my career |
| | Future | This won't help me in the future |
| | | This will help me in the future |
| | | This is something I will use in the future |
| | | This is something I will need in the future |
| **After** | | I won't use this again after this class |
| | | I won't need this again |

Table 6.3 to be used in a closed-response version of the survey (See Table 6.4).

Table 6.4: The following are the four LT statements used in the closed-response pilot survey (version 2).

| Reasoning Number | LT Statement |
|---|---|
| R1 | This will be important when working with patients |
| R2 | This is not something I need to know for my career |
| R3 | This will help me in the future |
| R4 | I will not use this again after this class |

One thing to point out about the above statements is that they vary in whether they are positive – 'I will need this' – or negative – 'I will never use this.' Although we would prefer for the statements to all be either positive or negative and not a mix, we also did not want to assume that either version of the statement was equivalent to the students (i.e., would we get the same types of responses from the positive version as the negative versions?). So, for the closed-response version, we decided only to use the formats that the students had previously used (e.g., the patient statements were positive, and the after statements were negative).

**Negotiated Experience:** Negotiated Experience statements broke down into two primary types: obligation – they did it because they had to; and tension in expectations – they disagree with the value put on something in the class. These are described in more detail in Chapter 4. Table 6.5 has example statements that came from the detailed analysis of the NE statements. The NE statements did not breakdown in the same way as the LT ones. Both sets of responses could be narrowed down into a few categories with representative examples, but the NE examples could not be further broken down into specific sentence structures. All of the representative examples of NE are a mix of negative and positive, i.e., 'it is useful for the future but not realistic for the class.'

Table 6.5: Summary of the outcome of the interview analysis, showing the number of sub-bins and questions for each practice.

| **Negotiated Experience - NE** | | |
|---|---|---|
| Components | Category | Examples |
| **Tension in Expectations** | Less important | It is not as important to me<br>It is not the most important thing for the students |
| | Somewhat important | It is important at times but there should not be so much emphasis<br>It is somewhat important but it doesn't apply to me |
| | Important but... | It is important to think about but it is not always necessary<br>It is useful for the future but not realistic for the class |
| **Obligation** | Personal preference | I only care about this because it is for a grade<br>I don't care about this but I felt obligated to do it for the class |
| | Value | It might be helpful but I felt forced to do it in the class<br>It will not help my career but I felt like I had to do it for the class |
| | Understanding | I did it for a grade even though I didn't understand it<br>I felt forced to do it even though it didn't mean anything to me |

Finally, Table 6.6 contains six statements that are representative of the typical NE responses found in the analysis. We decided not to use the Obligation-Understanding questions because in our experience ‘understanding’ is too broad and has too many possible interpretations (from interviews and open-response analysis).

Table 6.6: The final NE statements from analysis of Version 1

| Reasoning Number | NE Statement |
|---|---|
| R5 | It is not the most important thing to me |
| R6 | It is important at times but it does not apply to me |
| R7 | It is important to think about but not always necessary |
| R8 | I do not care about this but I felt like I had to do it for the class |
| R9 | It might be helpful but I felt obligated to do it in the class |
| R10 | This is important but I did it because I was expected to |

#### 6.3.1.3 A Note on Practices

It was unsurprising that the statements from different identity components were not evenly distributed across the different practices. The distribution coded in Version 1 of the survey can be seen in Table 6.7. Communicating and data analysis had the most statements across the board, and planning experiments had the fewest. Communicating was the largest source of NE statements, while LT was spread across communicating, data analysis, and understanding equipment. We ended up dropping the distribution of NE and LT across practices going forward for multiple reasons; the most straightforward was the logistics of only having specific identity stems connected to specific practice stems. Also, we want this survey to be broadly applicable outside our institution; we did not want to assume that all students would respond in the same way as those in DATA Lab.

## 6.4 Version 2 - Closed-Response Survey

Version 2 was sent out to a new population of students from a different institution, a highly selective university in the northeast of the United States. The primary goal of this version of the survey was to ensure that the interpretations of practices were representative of a different population. This version was also the first time the identity-specific reasoning questions were included; it was necessary to characterize how students interacted with those questions. In addition,

Table 6.7: Summary of the outcome of the interview analysis, showing the number of sub-bins and questions for each practice.

| | LT | NE | Other | Total |
|---|---|---|---|---|
| Communicating | 9 | 16 | 22 | 47 |
| Data Analysis | 10 | 8 | 23 | 41 |
| Executing Experiments | 7 | 6 | 4 | 17 |
| Group Work | 2 | 2 | 9 | 13 |
| Planning Experiments | 1 | 2 | 0 | 3 |
| Understanding Equipment | 9 | 8 | 0 | 17 |
| Total | 38 | 42 | 58 | 138 |

as before, a goal was to find items and questions that could be cut to reduce the survey into something that would be reasonable for students to take in the whole. Each item on the survey had a closed-response practice question (similar to Version 1) and then four reasoning questions (a random selection of the 10 possible developed in the analysis of Version 1). The four reasoning questions were consistent through the survey for each student, i.e., if student A had reasonings 4-7 for the first practice question, they had 4-7 for every practice question. Each student saw 10 items (meaning one practice and 4 reasoning questions) of the remaining 79 practice questions (see Fig. 6.6 and Appendix I). The survey was distributed through Qualtrics at the beginning of the spring semester in 2019 to students in four introductory physics courses at this northeastern university. The majority of the students were engineering or applied engineering physics majors. 353 responses in total. As we distributed this version of the survey to a new population of students, not life science majors, so we could not assume that 'patients' would mean anything toward their future. At the start of the survey, we asked, 'When thinking about your future career who do you imagine working with? (Doctors work with patients, teachers work with students).' We provided them with options to select: Patients, Students, Clients, and a fill in the blank. None of the other reasoning questions were altered.

Since this was a new population of students, six validation interviews were conducted to ensure that the students were interpreting questions as intended. This was also used as an opportunity

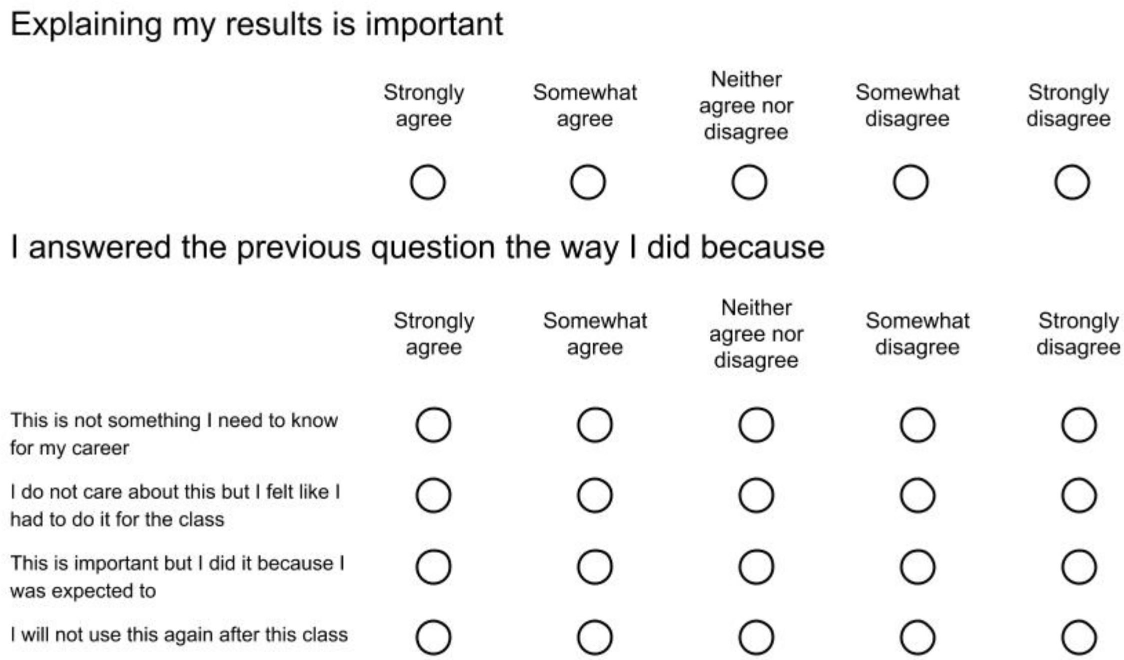



Figure 6.6: Example of an item from version 2 of the survey (Ref C4). The first part is the practice question, each student saw 10 of the 79. Then there are the identity reasoning questions, this part remained the same for all of the practice questions.

to discuss the identity reasoning questions and see how students understood them. No significant differences were found for practice questions, but the interviews did influence decisions concerning the identity-specific reasoning questions, which are described in the following section.

### 6.4.1 Version 2 Analysis

Reduction of survey responses was made with multiple cuts, as shown in Figure 6.4. The first set focuses on the practices and identifying similar wording and distributions of responses. The second set focuses on the identity reasoning statements and uses statistical analysis.

#### 6.4.1.1 Reduction of Practices

Since each student only saw 10 of the 79 practice questions, we were unable to do any substantial statistical analysis as we received fewer than 70 responses to each practice question. Questions were cut at this stage if they had similar distributions to similarly worded questions (e.g., two different group work focused questions about having help from their group were collapsed into one instead). The process is highlighted with the figures below; the first step was looking for similar distributions in responses (Fig. 6.7 and Appendix K).

The questions that had similar distributions were examined to see if the question statements were similar enough to combine, collapse, or remove. Once it was determined which questions in the group were reasonably similar, the choice had to be made about what could be collapsed (see Fig. 6.8 for an example). Questions were also considered for removal from the reverse direction. Starting with asking if the questions were asking nearly the same things, and then checking to see if the distribution of responses looked similar (Fig. 6.9). Finally, at this stage, questions were considered for removal based on the question statement themselves and whether or not the question was clear, concise, and specific; an example is shown in the Table 6.8 below. After the analysis at this stage, we brought the number of practice questions from 79 to 45.

Table 6.8: Question statement additionally evaluated.

| Question Statement | Removed | Reason for Removal |
|---|---|---|
| Agreeing as a group on how to complete a task before moving forward (ref GW22) | Yes | Not a critical practice, reflected in free-response statements, also ambiguous in what a preferred response would be |

#### 6.4.1.2 Identity

Since each student saw and responded to each of their four identity reasoning questions 10 times (one time for each practice statement), we were able to do more substantial statistical analysis as we had more than 1000 responses to each reasoning question. We used this statistical analysis to collapse the reasoning questions across, and within practices, the process is illustrated in Fig. 10 (statistics are detailed in Appendix F). Once it was confirmed that the reasonings could be combined across practice questions, we did the same pairwise analysis, but this time grouped by framework components, see Fig. 6.11 (LT is R1-4, and NE is R5-10).

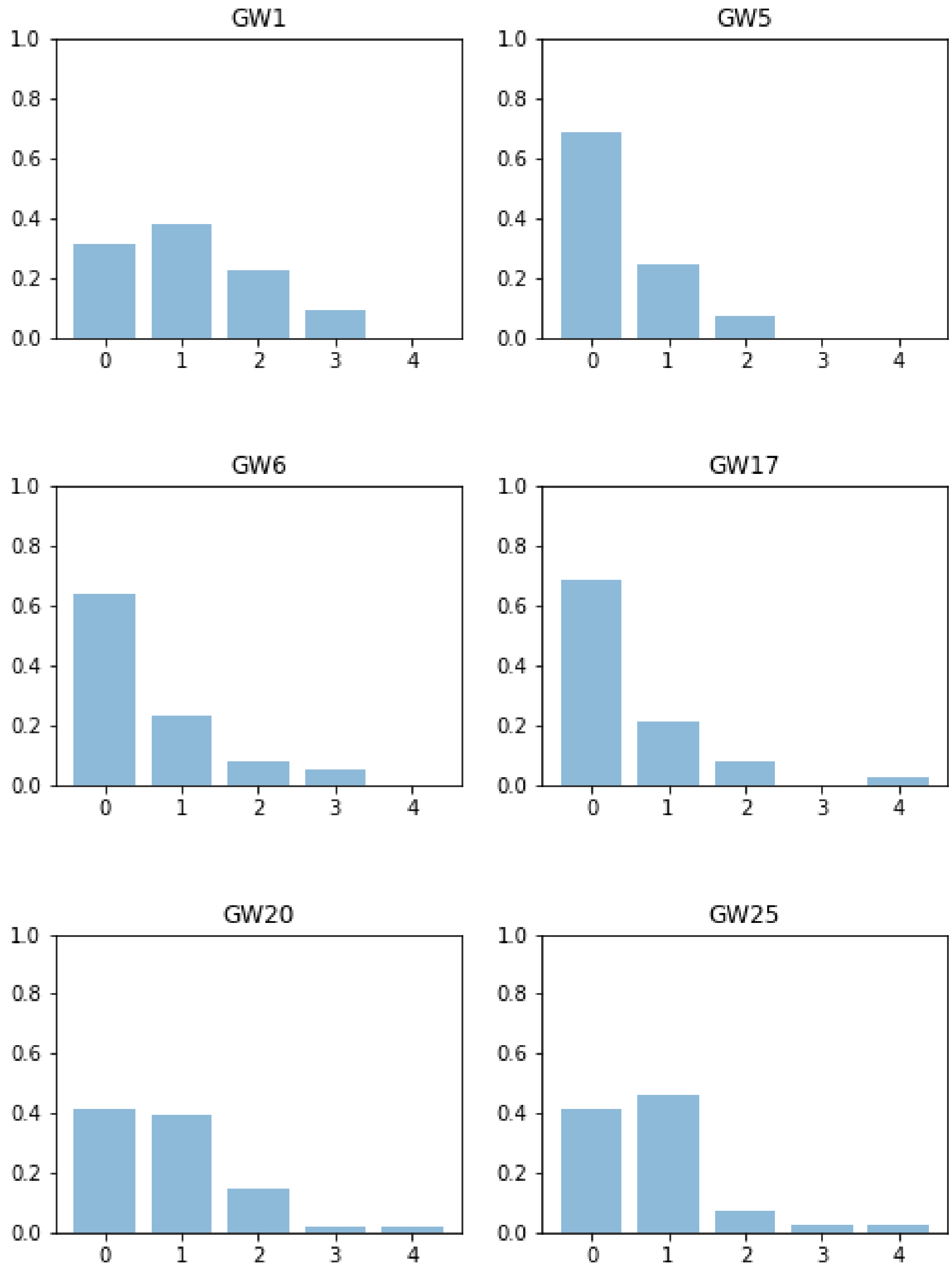



Figure 6.7: Six different GW questions to look for similar distributions of responses. Notice the similarities between GW5, 6, and 17. The responses are normalized to one. On the x-axis: 0 is Strongly agree, 1 is Somewhat agree, 2 is Niether agree nor disagree, 3 is Somewhat disagree, and 4 is Strongly disagree. (See Appendix G for the questions, and Appendix K for additional plots)

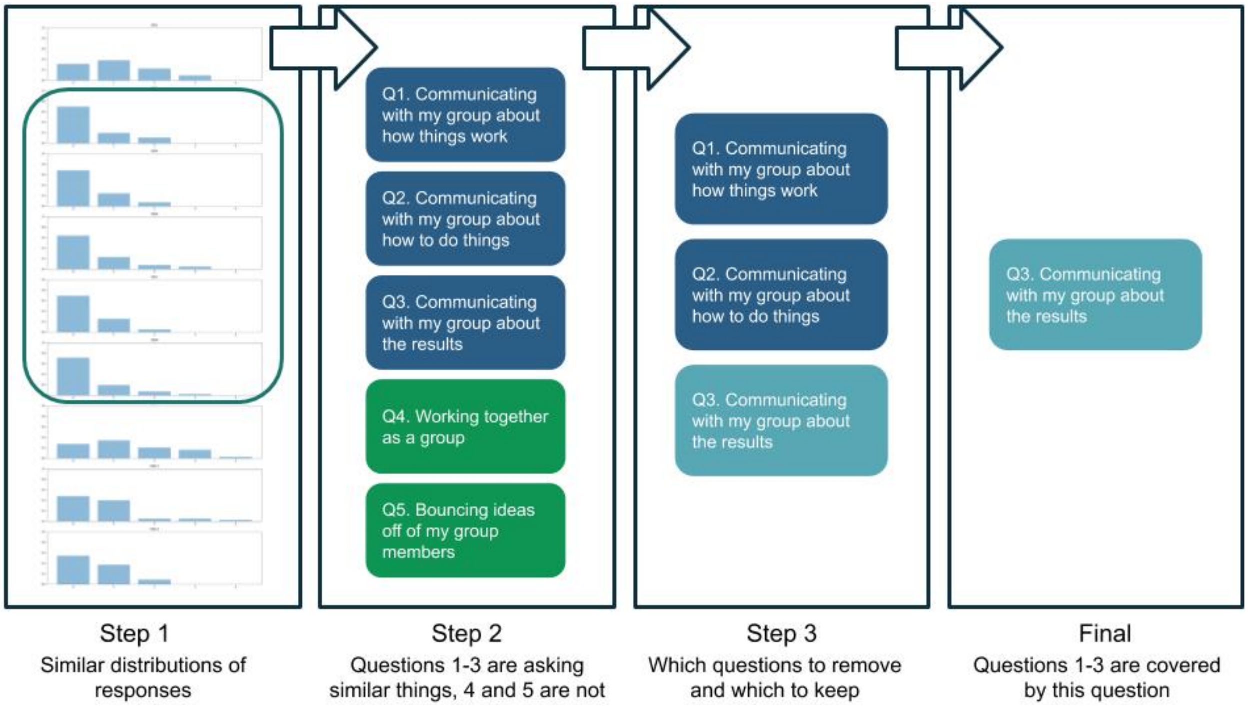



Figure 6.8: Illustration of the removal of questions based on similar distributions of responses. Step 1 shows the flagging of questions with similar distributions of answers. Step 2 shows the question statements being examined for similarities, the three blue questions were determined to be similar enough to be considered for collapse. Step 3 provides a closer look at the three related questions, the light blue (Q3) is the questions chosen to remain. (Reference numbers: Q1 is GW6, Q2 is GW7, Q3 is GW5, Q4 is GW19, and Q5 is GW17).

For the NE questions, within all six of the practices, we find significant similarities in the pairwise comparisons shown in Fig. 11, R5, 6, 8 and R7, 9, 10. Referring to the question statements in Table 6.9, it is easy to see that R5 and R6 have to do with relative importance, so as long as the resulting statement reflects the idea of relative importance, it should represent both of these well. R8, on the other hand, is an obligation statement and does not clearly fit with the other two, so we will hold off on collapsing or combining it here.

Taking a closer look at R7, 9, & 10, the three questions start with similar statements of value, 'important/helpful'. R9 and R10 both end with obligation statements, but R7 does not, it is more of an example of value vs. seeing value (Ch 4). There is also an interesting similarity between R8-10, they are all related to obligation in some way. Even with this similarity, there is an additional reason that may explain why R8 is not significantly similar to R9 and R10.

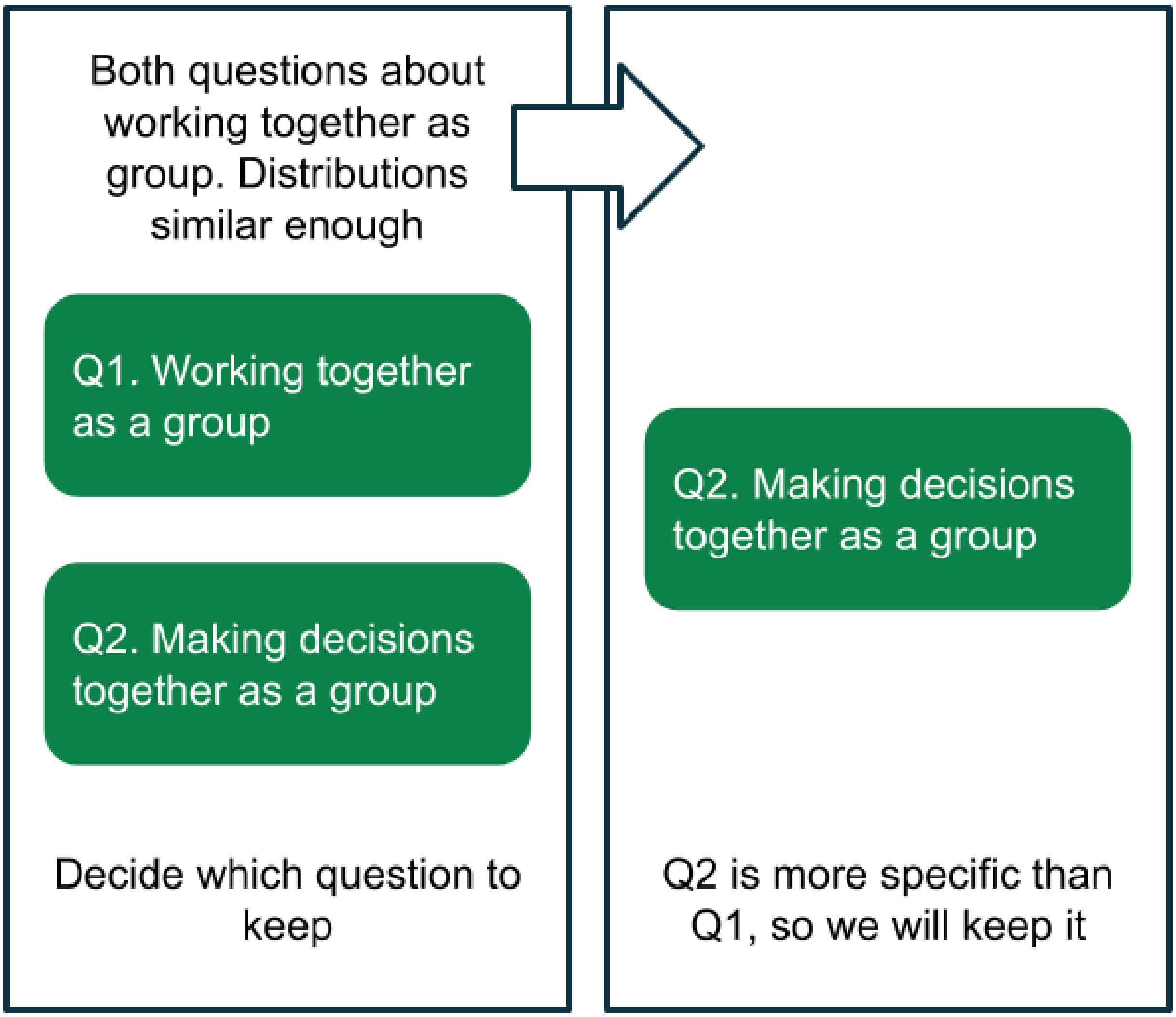



Figure 6.9: Similar questions being considered for removal. Here Q1 and 2 talk about groups doing things together, which is why they were considered for collapse. Their response distributions were similar enough to combine the questions. (Reference numbers Q1 is GW19 and Q2 is GW20).

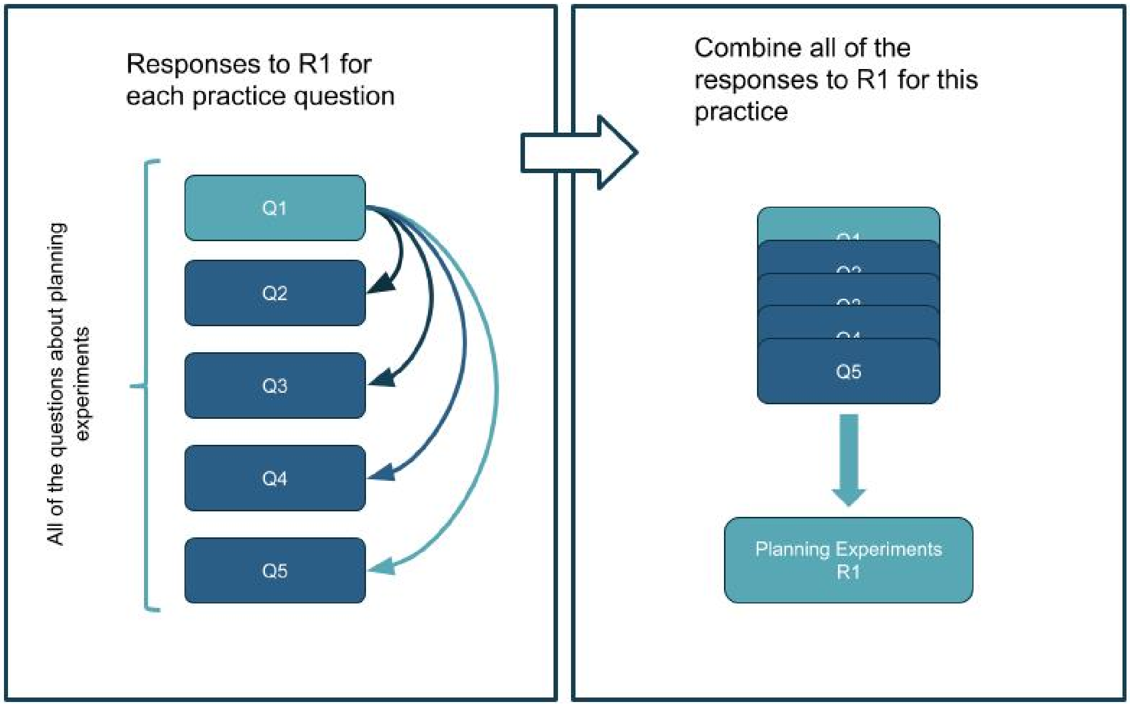



Figure 6.10: The initial step of analysis of reasoning questions. We had to confirm that it was reasonable to collapse the responses to each practice question by doing pairwise tests to make sure responses to R1 (This will be important when working with patients) were the same for each practice question.

The structure of these two statements, R9 and R10, are:

‘positive value statement’ + but + ‘obligation statement’

Whereas R8 is:

‘negative value statement’ + but + ‘obligation statement’

This may explain why the distributions are different. The obligation statements all originate from the same part of the NE theory and open-response analysis. So, dropping that statement is justified. At this point, we can collapse the original six NE statements into three (see Table 6.10). NE1 originates from the collapse of R5 and R6. It is just statement R5 because R6 could be interpreted as asking two questions, and it is essential to reduce confusion in the respondents. NE2 is the collapse of statements R9 and R10. A simple change was made to R10, we replaced ‘was expected’ with ‘had’ to leave flexibility in where the obligation comes from. For example, maybe the teacher expects it, or perhaps the student has personal ideas about doing physics, both are an obligation,

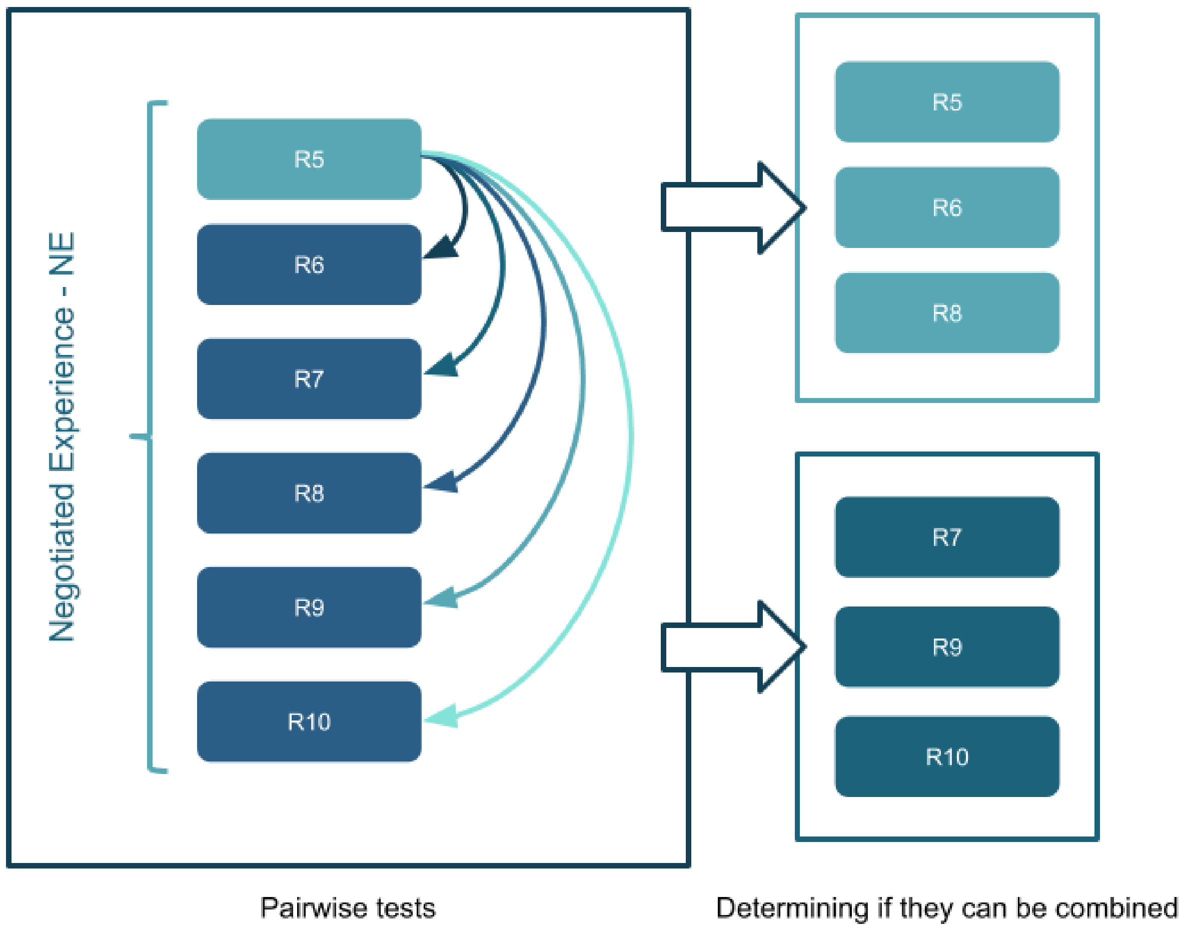



Figure 6.11: In the process of analyzing responses to the identity-specific reasoning questions, we did pairwise tests on the questions grouped into NE or LT. The analysis showed that R5, 6, and 8 and R7, 9, and 10 had statistically similar distributions, i.e., each group should be considered for collapse.

and neither is excluded in NE2. NE3 is just R7 since that statement did not appear to be collapsible with R9 and R10. We are currently leaving out R8 because it is mainly an obligation statement, which NE2 already is.

Two learning trajectory statements were significantly similar in each practice group, R2, and R4. We can examine them to determine if they should be collapsed. Comparing these statements (Table 6.9), both are negative, and both imply not needing the physics practice in the future. One of the validation interviews supports why these might collapse and not R3, which is ‘This will help me in the future.’ Based on the interview it has to do with the fact that ‘future’ by itself leaves open the context of what or when the future might be, whereas R2 and R4 tie to a specific context, even

Table 6.9: Reasoning statements used in Version 2 of the survey.

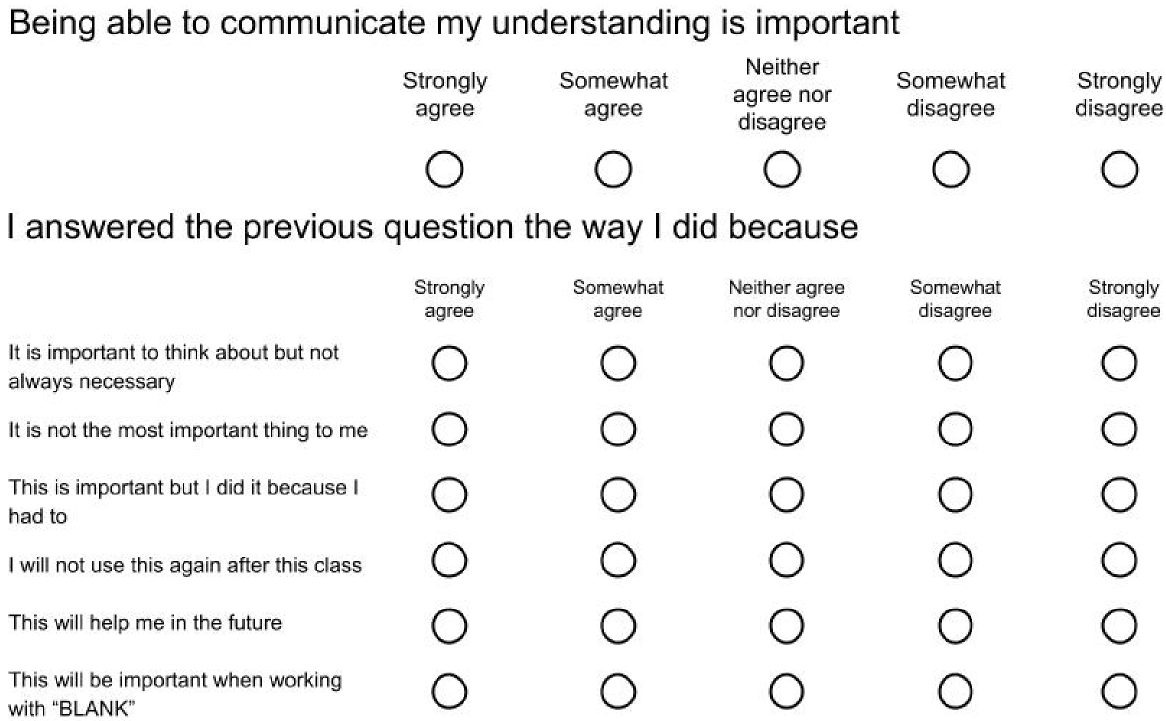
| Reasoning | Question Statement |
|---|---|
| R1 | This will be important when working with "BLANK" |
| R2 | This is not something I need to know for my career |
| R3 | This will help me in the future |
| R4 | I will not use this again after this class |
| R5 | It is not the most important thing to me |
| R6 | It is important at times but it does not apply to me |
| R7 | It is important to think about but not always necessary |
| R8 | I do not care about this but I felt like I had to do it for the class |
| R9 | It might be helpful but I felt obligated to do it in the class |
| R10 | This is important but I did it because I was expected to |

if R4 does it unintentionally. Student 5, talked about this in his interview, he said that by saying 'after this class' R4 is more tied to the context of school, so that would have framed his response. R2 clearly ties to a future career, as it is in the statement. Even though the context is different between the two statements, the fact that a solid context is provided might explain the similarity of the distributions. We kept R2 because the school context could be missed in the use of 'future' in R3.

The new LT reasoning questions are in Table 6.10. LT1 is R1 from the first version of reasoning questions. LT2 is the result of collapsed R2 and R4, it is the original R2, which includes a connection to the context of school. Then LT3 is the original R3. This analysis of the identity reasoning questions takes us from ten down to six, three for each component (NE and LT).

Table 6.10: The updated reasoning questions with their origins as described in this section.

| Label | Question Statement | Origin |
|---|---|---|
| LT1 | This will be important when working with "BLANK" | R1 |
| LT2 | I will not use this again after this class | R2 and R4 |
| LT3 | This will help me in the future | R3 |
| NE1 | It is not the most important thing to me | R5 and R6 |
| NE2 | This is important but I did it because I had to | R9 and R10 |
| NE3 | It is important to think about but not always necessary | R7 |



Being able to communicate my understanding is important

| Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|
| ○ | ○ | ○ | ○ | ○ |

I answered the previous question the way I did because

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| It is important to think about but not always necessary | ○ | ○ | ○ | ○ | ○ |
| It is not the most important thing to me | ○ | ○ | ○ | ○ | ○ |
| This is important but I did it because I had to | ○ | ○ | ○ | ○ | ○ |
| I will not use this again after this class | ○ | ○ | ○ | ○ | ○ |
| This will help me in the future | ○ | ○ | ○ | ○ | ○ |
| This will be important when working with "BLANK" | ○ | ○ | ○ | ○ | ○ |

Figure 6.12: An example item from version 3 of the survey (Ref. C12).

## 6.5 Version 3 - Closed-Response Validation

The third version of the survey was given to students in the second semester of the transformed labs for non-physics majors at the end of the spring semester 2019. 360 students completed the survey (a 60% response rate). The goal was to reduce questions to a number that would be reasonable for a student to answer all of (fewer than 30, based on the E-CLASS [1]). Each student saw 20 of the remaining 45 practice questions and all six reasoning questions. The structure was otherwise the same as Version 2 (see Fig. 6.12 and Appendix J).

### 6.5.1 Version 3 Analysis

#### 6.5.1.1 Practices - Final Reduction

Due to the reduction in the size of the survey, we were finally able to run pairwise tests of all of the questions within each practice (greater than 100 responses to each question). The majority of the distributions of responses within a specific practice are statistically similar; this implies that students are responding to the questions in the same ways so they can be combined (for distributions see Appendix L). Since the responses to these questions were statistically and visually similar, they were all accomplishing the same thing, i.e., not highlighting anything unique about working in a group, at least not that were showing up in student responses. This meant that any of them could be removed or collapsed. The choice of removal or collapse was made based on several criteria. First, if multiple questions were asking similar things, they should be collapsed, or all but one should be removed (just as in Version 2). Then the goal was to cover most of the breadth of interpretations of the practice with as few questions as possible.

The final step was different from the others because the goal was not to determine what questions could be removed but instead, which should remain. The questions that should remain were those that produced unique responses to the identity reasoning questions. To determine this, pairwise tests were run on the responses to each set of reasoning questions within a practice group; Fig. 6.13 illustrates this. The pairs that showed significant differences were examined (for details of the statistics see Appendix F). Practice statements that produced unique identity reasoning responses several times were deemed to be ones that must remain. This step was mainly a check to make sure questions that produced unique reasoning responses were not being removed.

The analysis of the practice questions brought the total from 45 down to 24, which is a reasonable number to expect students to answer as a whole instead of a subset.

#### 6.5.1.2 Identity

Pairwise tests were run on the identity-specific reasoning questions both within practice groups and across all responses (as in Version 2), in every case LT1 and LT3 were significantly similar (Table 6.10). Due to the statistically similar distributions, those two questions can be collapsed into one. LT3 will be kept because LT1 is more complicated and requires a fill-in-the-blank. None of the NE reasoning questions were statistically similar, so they cannot be collapsed at this time. Additional analysis will be necessary to determine if any can be collapsed or removed, but that is not possible at this time. The final five identity reasoning questions are in Table 6.11.

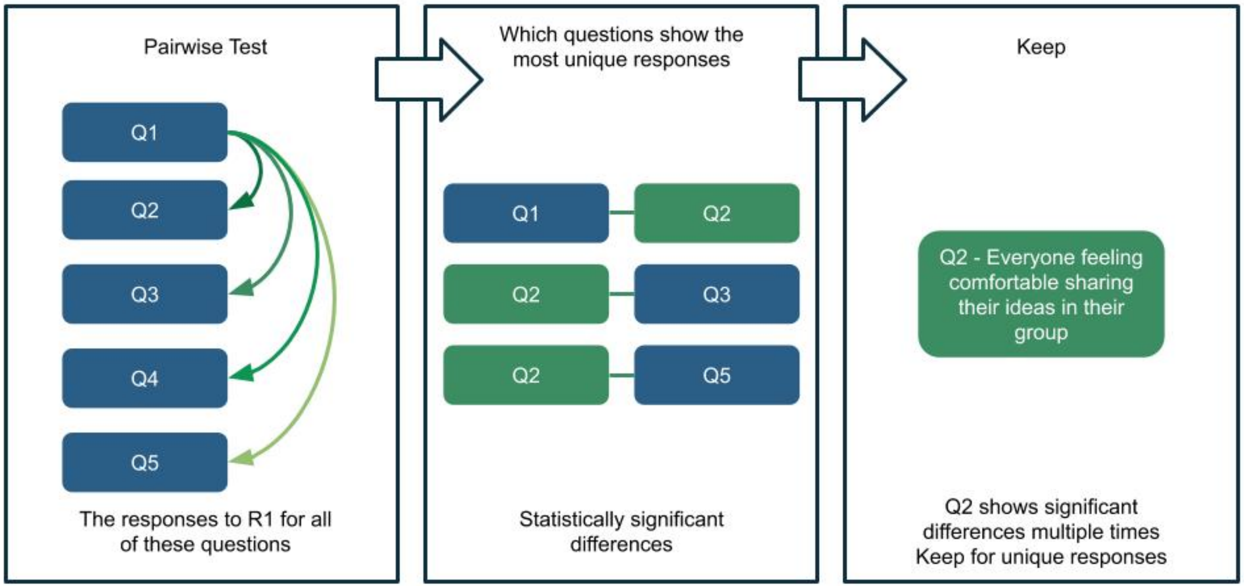



Figure 6.13: Showing the process for confirming that the practice questions that had unique reasoning responses were kept (Ref. GW9).

Table 6.11: The final five identity reasoning questions.

| Label | Question Statement |
|---|---|
| LT2 | I will not use this again after this class |
| LT3 | This will help me in the future |
| NE1 | It is not the most important thing to me |
| NE2 | This is important but I did it because I had to |
| NE3 | It is important to think about but not always necessary |

## 6.6 Discussion

Each stage of the survey development process, including all three distribution and analysis cycles, has lead to a fully-closed response survey with fewer than 30 questions, a reasonable number for students to complete in entirety. After the establishment of a theoretical framework for understanding labs, practices, and identity, the survey development process began with interviews to aid in the understanding of the ways students interpret different lab practices. Analysis of the interviews resulted in 108 questions covering the space of students' interpretations of the practices. Those questions were tested in an open-response survey (Version 1), the analysis of which reduced the number of practice questions to 79 and lead to the development of ten identity-specific reasoning questions. Version 2 of the survey was in part a test of those identity reasonings, but also of the survey in a new population of students. Through analysis of responses to Version 2, the reasoning questions were reduced from ten to six, and the practices from 79 to 45. Analysis of the final survey distribution discussed here, Version 3, culminated in a remaining 24 practice and five identity reasoning questions, a survey that can be reasonably completed by students in whole. (See Appindix M for complete list of questions in Version 4).

The goal of a fully closed-response survey has been reached, but work is still necessary to evaluate Version 4 quantitatively. A large number of responses are necessary to conduct analytics in order to begin to make claims about the results of the survey. Although the entire survey has been designed fully from student responses and interpretations and in alignment with a theoretical framework on identity, it is not possible to claim what responses to the survey tell us analytically about identity without additional quantitative work.

# CHAPTER 7

# CONCLUSION

This dissertation has laid out the picture of the work being done on physics labs and pointed to a pressing need, large-scale assessment tools (Chapter 2). This has included a discussion of the large scale lab transformation in the algebra-based physics labs at MSU (Chapter 3). The transformed lab course set the context for the study of how physics identity is connected to practices in lab classes and the development of a survey to measure that connection (Chapters 4, 5, and 6). The survey development process has lead to a fully closed-response version that can be reasonably taken in whole by students (see Appendix M). This final version has yet to be validated analytically, which is necessary before claims can be made about the responses.

If time allowed the next step would be to distribute the survey to a large number of students and run analytics to evaluate any correlations between different components, practices or identity. At this time we have a survey that has been developed and validated in alignment with student interpretations and the model of identity (as described in Chapter 4). Analytic validation is necessary before broad claims can be made about responses as a whole but the process of developing the survey in and of itself has produced significant insights. We have provided a method for producing assessment tools to measure other attitudinal and affective changes. We have shown that identity can be tied to experiences with practices and that the model used by Close et al. [21] cannot be directly applied to our context without adjustment.

In experience with this work it has been apparent that the traditional question, 'Do you see yourself as a physics person,' used as validation in other quantitative identity work, is an insufficient measure of identity in many cases. We are opposed to the dependence on this one question for one thing a single question should not be the sole validation of and identity assessment. Also, identity and identifying with physics is not nearly as simple as the 'physics person' question makes it seem. The students in the DATA Lab were mainly life science majors, the majority of whom would say in interviews that they do not see themselves as a physics person right before making a statement that reflects physics identity. Using the 'physics person' question to validate studies of physics identity greatly limits the scope of the work regarding who is being counted. It also narrows the possible understanding of physics identity, it is not limited to only perspective physics majors, anyone can identify with physics and ignoring that does a disservice to the broader population and to physics. Working to make physics education better for everyone is hindered when we ignore how the majority of people may identify with the field. Additionally, the goals of physics identity research do not need to be focused on getting and retaining more physics majors. Becoming a physicist does not and should not be the end goal of developing a physics identity. We physicists generally see physics as the foundation of most if not all studies of science, therefore we should see value in making that foundation more accessible to all who study science.

## 7.1 Future Directions

There are several aspects of the work that we were unable to pursue, for example we focused on only two components of the identity model in the survey development, learning trajectory and negotiated experience. We found evidence of community membership, interest, and the unclassified examples in the data but did not analyze them further. A more complete version of the survey would include reasoning questions that address at least community membership and interest. The 'physics person' question was included on Versions 2 and 3 of the survey. It would be interesting to see how that question correlates with other responses to the survey.

Most of the survey development was done in the context of the DATA Labs (Chapter 3), which inevitably influenced the direction of the work. The practices central to the survey, although not solely produced from responses of DATA Lab students, were undeniably affected by the course. As mentioned above, the DATA Labs and upper division labs at MSU did not emphasize the practice of computation (at the time of the interviews), which is a relevant practice in lab courses at other institutions.

The structure of the DATA Labs, both the course environment and the student population, also likely impacted the work in regards to identity. As discussed in Chapter 4, there was no evidence of competence or recognition in the student responses to the open-response survey and we hypothesize that this is likely due to the features of the course and the goals of the students. As an example, the course does not explicitly emphasize recognition from peers or instructors, and these students are not physics majors so recognition with regards to their physics skills is likely to be less important to them. We also expect that the community membership (CM) and negotiated experience (NE) responses found were influenced by the course context, as one for non-physics STEM majors. The NE responses were all negative predictably due to opposing perspectives about practices that the students must resolve. Additionally, we see CM as a step to follow NE and as students getting introduced to physics they have not had the time to move from the NE to the CM phase of identity development. The potential influences of the course context both in practices and identity is a relevant direction of additional future investigations.

During the analysis of Version 1 of the survey, we began looking at practice-specific responses that showed different levels of sophistication in application and understanding of the practice. For example, one student might say that understanding the equipment means they know how to use it for their purposes, while another student says they understand the equipment when they are able to adapt it to new situations. In this case the second student has a more sophisticated interpretation of the practice of understanding equipment. Like the other components of the identity model this area of analysis was dropped due to limited time and resources.

Another unutilized direction from Version 1 of the survey is all of the answers to the ‘for an experimental physicist’ open-response questions. We were again unable to do anything with that area of analysis due to time constraints, even with the substantial amounts of data.

## 7.2 Big Picture

For practitioners, faculty in charge of physics labs, the hope is that this dissertation put into focus the current state of undergraduate physics lab education. Labs need to move away from confirmatory and validation experiments, and away from the fixation on content learning. It is time that we take full advantage of the specific opportunities afforded to us through laboratory instruction. As shown in this dissertation, the practices and process of ‘doing physics’ have been goals of lab instruction since the beginning and yet we have struggled to realize those goals for just as long. Once practices are set as the goal for lab courses the design and assessment must follow (Funkhouser, 2019 [40] and Chapter 3). Part of the problem has been the disconnect between having practices as a goal and still assessing based on content. What those assessments look like is still an active area of research but there is enough out there to begin to turn the tide of labs in physics education. The DATA Labs described in Chapter 3 provide examples of this process for the learning goals specific to the course, but the steps can be followed with a variety of practices. For example, the faculty at MSU did not discuss computation as a goal for non-physics majors in the labs but there are plenty of situations where computation may become central to the course design. No matter the direction preferred by the program, progress in physics labs education must continue forward. Content learning has never been the strength of lab instruction and maintaining it as a goal is and has always been a mistake.

Understanding physics identity outside of field of physics is a valuable step in the direction of reaching more people. Lab environments can and should be utilized as a space for students to take agency over their learning. Since their inception in science education, the potential of labs have not been fully realized. Researchers and practitioners alike need to lean into the opportunities for engagement in the process of ‘doing science’ that are provided by lab environments. Let this be a reminder of where labs are going and also how important they still very much are in physics education. There is no time in the history of labs in science education that educators have used them to their full potential and there is no time like the present to change that.

# APPENDICES

# APPENDIX A

## DATA LAB EXPERIMENT DESCRIPTIONS

Descriptions of the DATA Lab experiments as discussed in Chapter 3.

Table A.1: DL1 Experiments

| Experiment | Main Idea |
|---|---|
| Workshop 1 | Taking a variety of measurements and determining the uncertainty |
| Workshop 2 | Taking simple measurements, learning how to plot parameters in useful ways, and incorporating uncertainty into analysis and results |
| Workshop 3 | Using the example of making a peanut butter and jelly sandwich to evaluate procedures and discuss proper documentation |
| Free Fall | Exploring free fall and terminal velocity with coffee filters |
| (In)elastic Collisions | Exploring elastic and inelastic collisions on an air track |
| Standing Waves | Exploring waves on a string, nodes, and resonant frequencies |
| Impulse | Exploring impulse with bouncing balls and relating that to concussions |
| Energy Transfer | Exploring energy loss of a bouncing ball |
| Pendulum | Exploring a simple pendulum |

Table A.2: DL2 Experiments

| Experiment | Main Idea |
|---|---|
| Ohm's Law | Measuring current and voltage to determine resistance of a resistor |
| Fields | Exploring electric fields, determining the number of electrons transferred between two pieces of tape |
| Transformers | Exploring solenoids and transformers, developing a formula to describe the relationship between voltage and number of turns |
| Resistivity | Exploring how resistance depends on length and width, determining the resistivity of clay |
| Charge-to-mass Ratio | Finding the charge-to-mass ratio of an electron |
| Biomeasures | Exploring an oscilloscope, measuring a heartbeat on the scope |
| Snell's Law: Rainbows | Exploring refraction of light, investigating Snell's Law and different wavelengths of light |
| Snell's Law: Fiber Optics | Exploring refraction of light, investigating Snell's Law and total internal reflection |
| Lenses | Exploring thin lenses, investigating how corrective lenses work with different eye impairments |
| Interference | Exploring interference and diffraction, investigating single and double slit diffraction |
| Polarization | Exploring polarizers, investigating polarization to come up with Malus's Law |

# APPENDIX B

## DATA LAB RUBRICS

These supplementary files provide insight into the assessments of the DATA Lab (Ch 3). What follows are the rubrics used in different aspects of the course to evaluate the students in relation to the learning goals.

# Design Analysis Tools and Apprenticeship (DATA) Lab Supplemental Materials

Rubrics and Descriptions

## Learning Goals

**Experimental Design**

*Communication: Clearly record the steps and results of the experiment.*
*Scientific Process: Proceed intentionally through the experiment.*

- Communication
    - Diagrams are labeled and clear
    - Procedure is clear and detailed enough to reproduce the experiment
    - Observations are noted and related back to the concepts
    - Predictions are listed and explained
    - Reasoning/motivation shows why the experiment was carried out in this manner
- Scientific process
    - List goals for each section of the lab
    - Did they plan ahead?
    - Did they work systematically? And intentionally?
    - Multiple trials
    - Attempts to improve accuracy

**Discussion**

*Uncertainty: Discuss uncertainty in measurements, models, and results.*
*Results: Present results in a clear way and support claims with evidence.*

- Uncertainty
    - Measurements
        - Recorded with uncertainty
        - Discuss sources of uncertainty
        - Uncertainty is quantified and explained
        - Worked to reduce uncertainty
    - Models
        - Compared models to observations
        - Discussion of limitations/assumptions of model
        - Corrections to model based on experimental results
- Results
    - Plot (if one exists)
        - They graph their data in a way that makes sense
        - The plot tells us something significant about the experiment
            - Not just, x and y are linearly related
        - There is a best fit line and a slope
        - There are error bars on the data points
            - Error bars that make sense
        - They graphed their data in an interesting way that tells us something about the experimental parameters
    - Conclusions
        - They discuss the motivation of the experiment

- They summarize the process
- They discuss the result
    - Slope or other significant result is given with uncertainty and compared to some expectation
- The significance of the result is discussed
- It is tied to the bigger picture (implications)

General grading strategy

- Combine
    - Did they do it at all?
    - Did they do it well?
- Overall things to look for
    - Communication, scientific process, uncertainty, and results

General grading scale:

2 (65) - Very weak notebook, they turned something in but that's about it

- Most categories are nonexistent and what is present is done poorly

2.5 (68-74) - Not great, they left out very important pieces of information completely and what they have needs a lot of work

- Many categories or aspects are left out and what is there needs major improvement

3 (78-84) - An alright notebook, they have some good stuff but it needs a lot of improvement

- Most categories are present but are missing some aspects. Some aspects are good but others need a lot of improvement

3.5 (87-92) - A good notebook, could use some more work

- All categories are present but there are some missing aspects or significant improvements to be made

3.75 (93) - A very good notebook, they just have a couple of things they could improve on

- All categories and most aspects are present but there are several aspects that have room for improvement

4 (96-100) - Perfect, I cannot think of anything else they could have done

- All categories and aspects are present and no further improvement is necessary

## How, and why, is in class work assessed?

**What's the purpose of this in class grading?** Everyone in this lab comes from a variety of backgrounds and have varying levels of experience with physics, lab equipment, and working in groups. The purpose of this In class grading is to allow for you to develop your abilities in engaging with lab equipment, describing the role of uncertainty in the experiment, communicating science to others, and collaborating effectively as a group member. As such, this rubric is not focused on if you are engaged in class, but rather on how you are engaged. This in class grade is not designed to make a big impact on your final grade in the course, it is to help develop abilities along these areas.

**How are numerical scores given?** The goal is for every student to improve their abilities along each of the areas listed in the rubric over time. The expectation is that as you develop your abilities, the expectations in the course will rise. So what was considered a 3.5 early in the course may not be the same as what a 3.5 is by the end of the course. This is a growing experience, and as such, we do not intend anyone to be experts at the start. Truth be told, there is no way to be "perfect" at science. However, by leveraging what we do well, we can focus on the things in which we need improvement and continuously grow.

**What's the purpose of the written feedback from the tutors?** Each day in the lab, the tutors will try to observe and notice how each student in their groups is doing in the areas on the rubric. After each day that you work on an experiment, you will receive feedback from the tutor on areas they would like to see you work as well as those they think you did well. The expectation is that, for future labs, you will work to improve in the areas the tutor noted.

**How are the tutors going to notice everything in this rubric?** It is not likely that every student will demonstrate everything in this rubric and that the tutor will notice everything. To help focus this, the tutors will approach each group with some questions related to the areas in the rubric to gauge understanding. The point isn't to notice everything you have done, but rather to get an idea of where you are currently and give you feedback and support to develop as time goes on.

**So how do I get a 4.0?** Unfortunately, there are no concrete examples of how to get a 4.0 because there is not one correct way to engage in class. Instead, there are many ways to conduct an experiment something we intend to value. In an attempt to remove some of the ambiguity, sample "ladders" of expertise are given below, as well as a graphical representation of the development tutors are valuing in this assessment. These should be taken as non-exhaustive lists but rather simple examples of one way in which development could occur. The best way to increase or maintain your grade is to pay attention to the feedback your tutors provide.

**Learning Goals**

**Group Function**

*Communication: Contribute to and remain involved in group discussions.*
*Collaboration: Come prepared and work well with your group.*
*Discussion: Work together to understand the result.*

- Communication
    - Engaged in group discussions
    - Asking/answering questions
    - Discussing plan with group
    - Explaining equipment to each other
- Collaboration
    - Come prepared
    - Actively participate in group work
    - Make sure everyone is on the same page
        - Don't move on too quickly
    - Try to come to a consensus
    - Ask for and give input
    - Attempt to get everyone involved
    - Don't dominate the discussion
- Discussion
    - Work together to understand results
    - Discuss implications of different experimental results or observations
    - Contribute helpful ideas in data analysis

**Experimental Design**

*Equipment: Engage with the equipment. Show competence in use of equipment.*
*Experimental Process: Employ good experimental practices.*
*Uncertainty: Take into account where uncertainty plays into the experimental process.*

- Equipment
    - Engage with the equipment
    - Actively involved in data taking
    - Able to troubleshoot equipment
    - Show competence in use of equipment
- Experimental process
    - Work systematically
        - Don't just randomly take measurements
        - Work with intention
    - Make predictions
    - Record observations and data
    - Set goals
- Uncertainty

- Work to reduce uncertainty in measurements
- Discuss and quantify sources of uncertainty
- Carry uncertainty through calculations
- Discuss model assumptions and limitations
- Compare results to expected

General grading scale:
2 (65) - Negatively impacted work of group and progress on experiment
2.5 (68-74) - Did not contribute in anyway to group's progress
3 (78-82) - Weak participation, still worked with group but needs a lot of improvement
3.25 (85) - Sort of average, not outstanding but solid effort
3.5 (87-90) - They worked well with their group but there are definitely places where they can improve
3.75 (93) - They were vital to their group's success but they could improve on some things
4 (96-100) - Perfect, I can't think of anything they could have done better

Communication Project Rubric

This rubric is intended to assess student proposals during the communication project day. The communication project homework rubrics helped inform the topics, and therefore should help expedite grading. Each section is equally weighted. Information provided in a proposal should cover both the work previously completed and the work that might emerge from it. This rubric intends to assess both aspects.

A previous communication project homework tasked students with critiquing proposals, everyone should be aware of both what is expected in a proposal as well as how to assess them, using feedback provided there to inform critique decisions and their assessment of others. While a complete proposal is expected, by the first project day, students have only received feedback regarding previous work. Therefore, the first proposal is likely to be stronger in that area. To account for this, the first proposal is weighted significantly less than the second. This activity and future homework assignments are intended to build further skills, culminating in the second proposal. As such, please make sure the feedback you provide is productive and useful to the students receiving it. Student-assigned feedback that does not meet this condition will not satisfy the “in class” portion of the project grade.

The grading breakdown for this day is as follows:

- 70% of the complete grade - Tutor-assigned feedback
- 20% of the complete grade - Student-assigned feedback
- 10% of the complete grade - In Class Portion: Completion of five (4) peer reviews for other students

All feedback will be returned to the students but will be returned anonymously. Both strengths and areas of possible improvement should be noted, with suggestions to successfully improve.

There is no intent to assess on “beauty,” and no benefit should be awarded for proposals that are visually more “appealing” or “official.” If images are included, no benefit or penalty should be included outside of clarity.

**Prior Work**
**[**4.0(100%) 4.0(96%) 3.5(88%) 3.0(80%) 2.5(72%) 2.0(64%)**]**
*Experimental Design: It is clear how the past data was taken.*
*Discussion: The document tells a complete story of the conducted experiment*

- Experimental Design
    - Method
        - The overall experimental method including pertinent equipment and critical procedural steps are included
    - Uncertainty
        - Discusses uncertainty in measurements, models, and results.
        - The quantitative data are presented with uncertainty
        - Sources of uncertainty are described
        - Deviations from the model are described
- Discussion
    - Communication
        - Motivation of previous work is clear
        - Figures are complete (axes, titles, units, error bars, etc.)
    - Results
        - Results from previous work are presented within experimental constraints
        - Reasonable conclusions and implications are drawn from the data presented
        - Data are presented effectively

**Future Work**
**[**4.0(100%) 4.0(96%) 3.5(88%) 3.0(80%) 2.5(72%) 2.0(64%)**]**
*Experimental design: It is clear how future data will be taken.*
*Discussion: The document discusses compelling future work.*

- Experimental Design
    - Method
        - Necessary or additional equipment is discussed
        - New experimental methodology is summarized
        - Reasons for conducting experiment in this manner are clear
    - Uncertainty
        - Future work has considered possible issues
        - Acknowledges concerns and complications
        - Considers potential solutions
- Discussion
    - Proposed investigation is original, but connected to and motivated from the previous work
    - There is a need for the future work
    - The proposal is compelling and well argued

Would you fund this project?
Yes No Requires further review

---

General grading strategy

- Combine
    - Did they do it at all?
    - Did they do it well?
- Overall things to look for
    - Communication, scientific process, uncertainty, and results

General grading scale:
2.0 (64%) - Very weak proposal, they turned something in but that's about it
2.5 (72%) - Not great, they left out very important pieces of information completely and what they have needs a lot of work
3.0 (80%) - An alright proposal, they have some good stuff but it needs a lot of improvement
3.5 (88%) - A good proposal, could use some more work
4.0 (96%) - A very good proposal, they just have a couple of things they could improve on
4.0 (100%) - Perfect, I cannot think of anything else they could have done

Communication Project Rubric

This rubric is intended to assess student presentations during the communication project day. The communication project homework rubrics helped inform the topics, and therefore should help expedite grading. Each section is equally weighed. Information during a poster presentation is conveyed in two ways  the physical poster and the oral discussion. Neither one can be complete without the other, and therefore this rubric is intended to cover both aspects.

While a complete presentation is expected, there has been feedback so far on communicating figures and the contents of an abstract. Therefore, the first poster presentation is likely to be stronger in these areas. To account for this, the first presentation is weighed significantly less than the second. This presentation and future homework assignments are intended to build further skills, culminating in the second presentation. As such, please make sure the feedback given is productive and useful to the students receiving it. Student-assigned feedback that does not meet this condition will not satisfy the “in class” portion of the project grade.

The grading breakdown for this day is as follows:

- 70% of the complete grade - Tutor-assigned feedback
- 20% of the complete grade - Student-assigned feedback
- 10% of the complete grade - In Class Portion: Completion of five (5) peer reviews for other students

All feedback will be returned to the students, but will be returned anonymously. Both strengths and areas of possible improvement should be noted, with suggestions to successfully improve.

There is no intent or desire to have students print formal posters for this event. Therefore, “beauty” is not an assessable aspect and no benefit should be awarded for posters printed in this way. “Tiled printing,” as discussed in the project information, is desired to cut cost and remove “beauty” as an element. Black and white, taped together pages forming a complete poster is more than sufficient.

**Experimental Design**
**[**4.0(100%) 4.0(96%) 3.5(88%) 3.0(80%) 2.5(72%) 2.0(64%)**]**
*Communication: It is clear how the data were taken.*
*Scientific Process: Proceed intentionally through the experiment.*

- Communication
    - The overall experimental method is described
    - Pertinent or unique equipment is described
    - Critical procedural steps are explained
- Scientific process
    - Reasoning/motivation - Is it clear why they conducted the experiment this way?
    - Quantitative data are presented with uncertainty
    - They worked to reduce the uncertainty

**Discussion**
**[**4.0(100%) 4.0(96%) 3.5(88%) 3.0(80%) 2.5(72%) 2.0(64%)**]**
*Uncertainty: Discuss uncertainty in measurements, models, and results.*
*Results: Present results in a clear way and support claims with evidence.*

- Uncertainty
    - Measurements
        - Discuss sources of uncertainty
        - Uncertainty is quantified and explained
    - Models
        - Deviations from the model are described
        - Discussion of limitations/assumptions of model
- Results
    - Plot
        - They graph their data in a way that makes sense
        - There is a best fit line and a slope
        - There are error bars on the data points
        - They graphed their data in an interesting way that tells us something about the experimental parameters
    - Conclusions
        - They discuss the results
            - Slope or other significant results are given with uncertainty and compared to some expectation
        - The significance of the results are discussed
        - It is tied it to the bigger picture (implications)

**Presentation**
**[**4.0(100%) 4.0(96%) 3.5(88%) 3.0(80%) 2.5(72%) 2.0(64%)**]**
*Poster: The poster tells a complete story in a way that is easy to follow.*
*How they presented: The presentation tells a complete story that is engaging.*

- Poster

    - The poster is structured in a clear way
    - The figures are appropriate for the data
    - Figures are complete (axes, titles, units, etc.)
    - Poster is easy to read with a mix of figures and text
- Their presentation
    - The flow of the discussion is clear and connected
    - The presentation is engaging
    - The experiment is described so that those who did not conduct it can understand
    - They are able to answer questions related to the study

---

General grading strategy
- Combine
    - Did they do it at all?
    - Did they do it well?
- Overall things to look for
    - Communication, scientific process, uncertainty, and results

General grading scale:
2.0 (64%) - Very weak project, they turned something in but that's about it
2.5 (72%) - Not great, they left out very important pieces of information completely and what they have needs a lot of work
3.0 (80%) - An alright project, they have some good stuff but it needs a lot of improvement
3.5 (88%) - A good project, could use some more work
4.0 (96%) - A very good project, they just have a couple of things they could improve on
4.0 (100%) - Perfect, I cannot think of anything else they could have done

## CPHW Motivation

When thinking of conducting an experiment, there are some aspects that easily come to mind: set up the equipment, collect and analyze the data, and determine what can be interpreted from the results. What is often forgotten, but equally important, is presenting these results to the greater scientific community. Twice in the semester, you will be asked to develop a proposal that emerges as a result of your experiments.

Because proposals are potentially new to you, there will be a series of homework problems that are intended to help you develop your proposals as the semester goes. For each submission, your tutor will provide brief feedback on your successes as well as ways to improve. While proposals may seem foreign, being able to sell yourself or your ideas probably doesn't.

## Figure/Caption

In this assignment, you will submit a figure and a caption that represents the data and results from your most recent experiment. More often than not, this figure will take the form of a graph. The rest of this description will use a graph as the example. However, the results of your specific experiment might not be best demonstrated using a graph. Consider your data and your experiment carefully as you prepare your figure.

For full credit, your figure should represent your results effectively and clearly. This should include a caption that describes your figure, discusses the uncertainty in your results, and discusses a conclusion or an implication that can be drawn from the analysis. Your figure will likely include a fit and comparison to a model, which should be discussed in the caption as well.
Writing a good caption is not trivial it is important to include the relevant information while maintaining brevity. Your caption should be concise aiming for 2-3 sentences and roughly 50 words.

Upload your CPHW on D2L.

## Grading Rubric

Four grade options
0 - Nothing submitted
3 - Submitted but not of high quality
4 - Could use improvement
5 - High quality work submitted

Emphasis on written feedback

Graph - Out of 5
- Communication
    - Graph demonstrates the data clearly
    - Graph provides insight into the parameters beyond a linear relationship
- Uncertainty
    - Error bars are included
    - Outliers are removed from fit

Caption - Out of 5
- Communication
    - Discussion of what is being plotted
    - Comparison to a model
    - Conclusions/implications are drawn from and supported by data
- Uncertainty
    - Deviations from the model are addressed
    - Analysis includes uncertainties

## CPHW Motivation

When thinking of conducting an experiment, there are some aspects that easily come to mind: set up the equipment, collect and analyze the data, and determine what can be interpreted from the results. What is often forgotten, but equally important, is presenting these results to the greater scientific community. Twice in the semester, you will be asked to develop a proposal that emerges as a result of your experiments.

Because proposals are potentially new to you, there will be a series of homework problems that are intended to help you develop your proposals as the semester goes. For each submission, your tutor will provide brief feedback on your successes as well as ways to improve. While proposals may seem foreign, being able to sell yourself or your ideas probably doesn't.

## Abstract

During the last three weeks of class, you have participated in workshops that focused on a number of important experimental concepts. While participating and engaging with these activities introduced you to experimental concerns, being able to synthesize that information and determine what is relevant moving forward is important when trying to understand and implement experimental practices. Summarizing the work you have previously undertaken is a meaningful exercise in scientific communication, and scientists often write abstracts - single paragraph summaries - to do so. A successful abstract is one that not only presents the major results of the work, but also informs the reader of the experimental methods, motivation of the experiment, and what those results tell us about our world.

A main aspect of an abstract is how much it explains in so few words  there is very little that can be taken out of an abstract without changing the meaning. Most written scientific communication starts with an abstract because it informs the readers of the most important aspects of the work, allowing the reader to choose whether or not to continue reading. Therefore, the trick of writing an abstract is that, typically, all of this is contained in **300 words or less.**

For this Communication Project Homework, you are tasked with writing an abstract about your experiences in the workshops. It can either be written about the workshops as a whole or about a specific one, but it should tell a complete story of the experiment. A reader of your abstract should be able to understand what you are doing in your experiment and why, the way you conducted your experiment, what the results were, and conclusions that can be drawn from these results in the bigger "science picture."

Upload your CPHW on D2L.

## Grading Rubric

Four grade options
0 - Nothing submitted
3 - Submitted but not of high quality
4 - Could use improvement
5 - High quality work submitted

Emphasis on written feedback

Experimental process - Out of 5
- Motivation
    - It is clear why the experiment was conducted
    - The goals and objectives are clear
- Experiment
    - It is clear how the experiment was conducted
    - Critical pieces of equipment and critical steps of the procedure are addressed

Discussion - Out of 5
- Results
    - Quantitative results, including uncertainty, are presented clearly
    - Sources of uncertainty are presented and relevant
- Conclusions
    - Implications that can be drawn from the data are clearly discussed
    - Deviations from model are discussed
    - Results are connected to the bigger picture

## CPHW Motivation

When thinking of conducting an experiment, there are some aspects that easily come to mind: set up the equipment, collect and analyze the data, and determine what can be interpreted from the results. What is often forgotten, but equally important, is presenting these results to the greater scientific community. Twice in the semester, you will be asked to develop a proposal that emerges as a result of your experiments.

Because proposals are potentially new to you, there will be a series of homework problems that are intended to help you develop your proposals as the semester goes. For each submission, your tutor will provide brief feedback on your successes as well as ways to improve. While proposals may seem foreign, being able to sell yourself or your ideas probably doesn't.

## Critique

For this Communication Project Homework, you are tasked with critiquing a proposal already completed. Giving and receiving critical yet constructive feedback is a skill that, with practice and reflection, can result in higher quality work. By thoroughly critiquing others work, you can find areas of your own work that may require additional attention and support. Meaningful critique usually contains two main points: recognition of strengths within the work as well as identification of opportunities to improve the work. Like writing about your own work, it is important to be clear and unambiguous  the receiver of your work should be able to understand your comments and improve the work from them. Therefore, it is important to identify specific examples that demonstrate the areas you are emphasizing.

A very strong critique will also suggest strategies intended to improve the work. Like many other aspects in this class, providing the necessary resources for growth is critical. Even though you will not resubmit proposals after receiving feedback, you will be writing two throughout the semester. Therefore, while specific improvements are useful, the author should be able to understand the reasoning behind the comments and scores so that they can incorporate them in their next proposal.

Samples of proposals are located on D2L. In these samples, the authors have written about work that goes beyond the content covered within Physics I. While the concepts covered may be different from what you've experienced in this class or in lecture, the document should still be written for scientists. Therefore, even if the science discussed is new or unknown, how the experiment was undertaken should be clear as should the results, conclusions, and rationality between the two. The rubric you will be using to critique the proposals, which is the same rubric by which your proposals will be assessed, is provided on D2L.

Upload your CPHW on D2L.

## Grading Rubric

This is the rubric that will be used to grade **your critique.** See D2L for the rubric you should use to critique the proposals.

Four grade options
0 - Nothing submitted
3 - Submitted but not of high quality
4 - Could use improvement
5 - High quality work submitted

Emphasis on written feedback

Identification - Out of 5
- Areas of growth
- Areas of success
- Detailed examples
- Suggestions for improvement

Feedback - Out of 5
- Comments are reflected in the scores
- Magnitude of success or need for improvement is signaled in the scores

## CPHW Motivation

When thinking of conducting an experiment, there are some aspects that easily come to mind: set up the equipment, collect and analyze the data, and determine what can be interpreted from the results. What is often forgotten, but equally important, is presenting these results to the greater scientific community. Twice in the semester, you will be asked to develop a poster and present out a result from your experiments  one from Electricity/Magnetism and one from Optics.
Because presentations like these are potentially new to you, there will be a series of homework problems that are intended to help you develop your poster as the semester goes. Your instructor will provide brief feedback on ways to improve your submissions, helping develop your overall poster presentation.

## Background

Through the process of creating and presenting a poster, many of you conducted your own background research to help you connect to your research. This process is very important and is something we hope to see more of on your second poster. The work we do in lab is rarely enough to fully understand the research  we need to investigate outside the lab, too.

Literature Review
For this Communication Project Homework, you are tasked with undertaking a literature review background research using credible and reliable sources  to motivate your work. Through expanding your knowledge base, you will be able to not only understand your work better but also to communicate it more effectively. We are asking you to find **at least 3** sources that you can reliably cite. These may provide background information into the experiment, support physics concepts, connect the work to "real life" situations, or provide applications that you may find interesting. These sources should help provide motivation for further study of this experiment.

Summary of Review
Then, write a short (one page) summary that communicates the big takeaways from your review how was that work relevant and related to the work you did in lab, what motivated the study, how is it connected to the real world, what are the limitations to these applications  citing your sources as appropriate. Finally, use this information, as well as the work you conducted in class, to define an interesting research question that you would pursue given more time in lab. Please note what equipment or type of methodology you would use to investigate this question. Please comment on the feasibility of conducting that experiment in this lab  would you be able to given our resources, or would you need more?

Upload your CPHW on D2L.

## Grading Rubric

Four grade options
0 - Nothing submitted
3 - Submitted but not of high quality
4 - Could use improvement
5 - High quality work submitted

Emphasis on written feedback

Sources - Out of 5

- Sources are credible and relevant
- Background
    - Connection to work done in the lab is clear
    - Relevant work conducted previously is explained
    - The motivation is clear
- Real-life connections
    - Discusses connections between implications and fundamental physics
    - Limitation of applicability

Future Research - Out of 5

- Communication
    - Related to work done in lab
    - Focused and clear
- Equipment
    - Major equipment and methods are discussed
    - Feasibility of experiment is considered

## Motivation

Scientists strive to remain objective in their research, drawing logical conclusions from their data and analysis rather than individual views or beliefs. Scientists interpret their results under some existing framework (e.g., Newton's Laws). These interpretations are often communicated to the scientific community and are presented using that framework from their perspective as the scientist conducting the research. These findings are validated and vetted by the research community.

The general public often receives their scientific news from media outlets and social media, but these sources are typically less objective as the science they present. In this way, bias from media sources or journalists can influence the scientific arguments they publish. Therefore, in order to obtain the information closest to what was reported, it is incumbent on the general public to interpret and critique the media they consume.

For this project, you and your group are tasked with critiquing two sides of a scientific issue that has been presented to the public. The topic you choose is up to you but should be discussed and agreed upon before coming to class for the day. You are to read both articles and, with your group, determine the arguments presented and how they are being supported.

To fully critique an argument, you need to read and consider both sides of it with an open-mind. Analyze it from your perspective as a budding scientist – think about the claims that each article makes, what supporting evidence is provided, and what rationale is used to connect the evidence to the claims. At the end of class today, you will hand in one typed copy of your group's critiques, which should consider both sides of the topic your group chose.

The expectations of each critique are detailed below.

## The Critiques and Assessment

Below is a breakdown of what is expected in each critique and the scores carried. You and your group should turn in one typed copy of your project, which includes a critique of both sides of the argument.

- Each side of the debate will count for 45% of your total grade, and each side should follow the structure below:
    - Review of the argument (20% total, as broken below)
        - What are the claims being made? (5%)
        - What evidence is being used to make those claims? (5%)
        - How is the claim linked to the evidence? (5%)
        - What assumptions or limitations do these claims work under? (5%)
    - Assessment of the argument (25% total, as broken down below)
        - Address the validity of the evidence (5%)
        - Discuss the logical reasonability of the connections between evidence and claim (5%)

        - Determine the applicability of the assumptions and limitations (5%)
        - What are the strengths of the article? (5%)
        - What are the weaknesses of the article (5%)
- Overall summary of the debate (10% of the total grade, broken down below)
    - Summarize the issue considering all sides, including why there are multiple conclusions that can be drawn (5%)
    - What does your group conclude about this scientific debate? Are there unresolved disagreements within your group? (5%)

## Topics and Articles

Here is a list of topics, with counter-point articles, that you may choose from. However, if you and your group decide to discuss a different topic or different articles within a topic, please discuss this (and which articles you have found) with your tutors.

Alternative Energy
Viewpoint 1
Viewpoint 2

Autism and Vaccinations
Viewpoint 1
Viewpoint 2

Climate Change
Viewpoint 1
Viewpoint 2

Genetically Modified Organisms (GMOs)
Viewpoint 1
Viewpoint 2

Medical Marijuana
Viewpoint 1
Viewpoint 2

Red Meat
Viewpoint 1
Viewpoint 2

## Motivation

Design a DATA Lab experiment

- **Goals**: Communication with peers and tutors, Experimental design
- **Output:**
    - Overview of a new DATA lab experiment
        - Outline
        - Goals
        - Uniqueness of experiment
    - Tutor document
        - Explain the physics
        - Where may complications may arise/ how can you solve them
        - Thought questions for the students

## The Documents

***Experiment Overview***

This is an outline that will be used to create the write up for the new experiment.

- **Outline of the experiment -** What equipment is necessary? What is involved in the experiment? What is the expected procedure? What observations are you hoping the students make?
- **Goals -** What are the goals of the experiment? Why do it? What are they trying to find? How does the experiment ensure that the goals are met? What do you want students to learn from this? Provide predicted results.
- **Uniqueness -** It builds off of previous experiments but does not replicate them. Differences from previous experiments are clear and highlighted. Why is this experiment uniquely qualified to achieve the learning goals?

***Tutor Document***

In DATA lab we have tutors who help students progress through the experiments. It is important for them to have a document that gives them the information they need and helps them handle issues when they come up.

- **Physics concepts** - What physics concepts are you trying to demonstrate? All necessary concepts should be detailed. Do not assume the specific physics knowledge of the tutor. Provide the information that they will need to have in order to help the students. Include the necessary physics equations. Connect the physics ideas to the bigger picture.
- **Complications** - What complications may arise and how can you solve them? Describe any difficult parts of the experiment and how to deal with them. Include any tips and tricks for the experiment.

# APPENDIX C

# INTERVIEW PROTOCOL

This appendix contains the protocol used for the interviews discussed in Chapters 4, 5, and 6. The interviews were semi-structured therefore the protocol were only a guide and were not necessarily strictly followed. Three different protocol are included, the first was used when interviewing students from the DATA Labs. The second protocol was adapted from the first and used for interviews with upper division physics students and students in the untransformed introductory algrabra-based physics labs. The third protocol comes from the survey validation interviews that were conducted at the highly selective northeastern university, where Version 2 of the survey was distributed (Sec. 6.4).

**Original** (DATA Lab Students)

---

Tell me about you
- your major
- why did you choose that
- what's your favorite class

How would you describe your physics lab to a friend who was thinking about taking it?

How do you think your instructor would describe it?

Can you walk me through a day in the lab? [How does class start, what do you do?]

What is challenging in the day-to-day of the lab?

What does it take to succeed in the class?

In the DATA labs you get written feedback right? Do you find it useful? Why do you think they do that?

Is there anything you struggled with in the course?

What was something you found really exciting?

I am going to list some things and for each one I would like to know what they mean to you and how important you think they are for the class.

- Group work
- Uncertainty
- Understanding the equipment
- Planning your experiment
- Communicating your results
- Asking questions
- Trying things

Is there anything that you would like the designers of the lab to know?

Is there anything else you would like to share about your lab experience?

---

**Final Version** (Upper Division and Not DATA Lab Students)

---

Name:

Tell me about you,
- your major
- why did you choose that
- what are your future goals
- what's your favorite class

Can you tell me a bit about this physics lab? [big picture, how long is an experiment, what do you turn in, etc.]

Can you walk me through a day in the lab? [How does class start, what do you do?]

What does it take to succeed in the class?

Can you describe a time where it really felt like you were doing physics? [Do you feel like you're doing science in the class?]

Do you feel like you are a physicist?  Would you call yourself a physicist?

I am going to list some things and for each one I would like to know:
- What they mean to you (What you think of when I say it)?
- How important is it for you?
- Do you feel like you do this? Can you do this?
- How important you think they are for the class?
- Is this an important part of doing physics?

- Group work
    - Does your partner trust your input?
- Uncertainty
- Understanding the equipment
    - Do you usually feel like accomplish this?
- Planning your experiment
- Executing the experiment
- Interpreting your results
- Answering your research question
- Communicating your results
    - Do you feel ownership over your lab work?
- Asking questions
- Trying things

Is there anything else you would like to share about your lab experience?

Do you have any questions for me?

---

Extras
Tell me a bit about your experience in the physics department here.

How would you describe your physics lab to a friend who was thinking about taking it?

How do you think your instructor would describe it?

What is challenging in the day-to-day of the lab?

Is there anything you struggled with in the course? [Can you describe a time where you really struggled with something in the course?]

What was something you found really exciting?

---

**Survey Validation Interviews**

---

(As transcribed from my notebook and memory)

- Tell me about yourself
    - Physics classes
    - Other classes
    - Physics labs
- What are your future career plans
    - Survey response:

- Thank you for taking the survey, I would like to ask you about some of your responses
- Take a look at these, remind yourself of what you were thinking when you answered
- I would like to go through and talk about your response to each question
    - Practice question:
        - Why did you answer this way
        - How did you interpret this question
    - Reasoning question:
        - How did you interpret this reasoning question
        - Why did you answer this way for this practice question

- Did you feel like all of the relevant practices for the lab were represented in the survey questions
- Did you feel like the reasonings provided were representative of your own thinking
    - Would something else have fit better
- You actually received 4 of the 10 possible reasonings, please take a look at these and let's talk about how you interpret them and if you would have answered them differently than what you already did

- Is there anything you would like to share
    - about your experience of taking the survey
    - About your experience in the physics department here
    - Anything else

- Do you have any questions for me

# APPENDIX D

## CODEBOOK

This appendix contains the codebook disccussed in Chapter 4 and used by the external research to test interrater reliability. The identity components come from the adaptation of the model from Close et al. [21] as described in Chapter 4.

# Identity Codebook



# Introduction

This codebook is for the process of developing survey questions to ask about identity.
- It is not for understanding how a particular student identifies with physics
- It is meant to define the features of identity statements of different types, that can then be turned into question for a survey on identity

All of the statements are tied to a specific practice, contained in the question statement
- This codebook wouldn't capture pre statements before students have specific practices to tie their responses to (e.g. at the beginning of the semester)
- This codebook will not be useful in any sort of pre/post analysis of responses
  - Although the outcome, a survey, should be

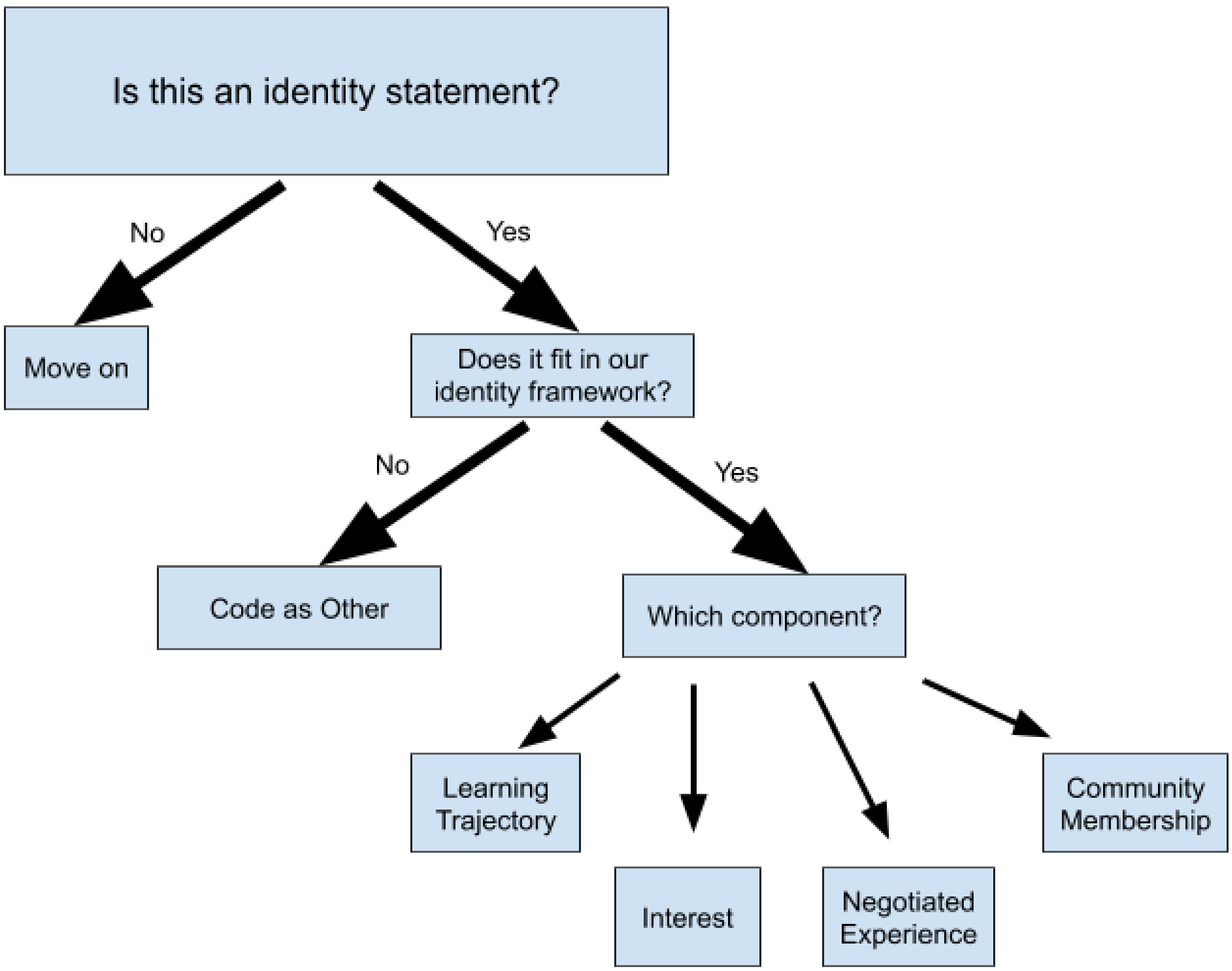
## Notes on coding

Each response should be coded in full

- Although it is helpful to indicate the components of the response that make it fit into a specific code

Responses may be coded as more than one thing

- If this becomes an issue we will reassess




---

# Identity Statements

## Requirements

- Connected to an experimental physics practice

    - *This practice*
- Includes a personal value statement
    - *This practice is valuable*
- Connects back to the identity framework
    - Generally speaking this should explain the value statement
    - *This practice is valuable because of this reason*

Note: The pieces of the requirements may also be pulled from the question statement
- Q: *This practice is valuable*
- R: *Because of this reason*

---

# Experimental Physics Practices

The names we use here are broad titles, the applications of the practices branch out from these as interpreted by the students in the interviews
- Communicating
- Working in a group
- Analyzing data
- Understanding equipment
- Planning experiments
- Executing experiments

---

# Identity Codes

- **Learning Trajectory**: The value they put on the practice is connected to their future or their planned career
- **Interest**: Indication of personal interest or preference for something
- **Negotiated Experience**: Dealing with (or adapting to) the expectations and value of the experimental physics community. Negotiating how those values and expectations align (or not) with one's own
- **Recognition**: Receiving recognition for performing physics practices and showing competence in them
- **Community Membership**: The value of the practice comes from the community
- **Competence**: Perceived competence in practices valued in the community
- **Other**: I am not sure where these fit but there are still identity statements

---

## Learning Trajectory

The value they put on the practice is connected to their future or their planned career

- i.e. I want to be a doctor, so I value things that will be helpful for me as a doctor

## Indicators

Future

They say something about their future or how they may use this practice in the future

- Referring to future career/profession or plans
- Transferable or relevant to their future
- Cues: future, career, profession, med school, patients

**Q**: Determining patterns from my data
**R**: it is not so important to look for trends in data because overall it is only a small part of what I am studying for my degree and will not necessarily help me in *my overall career*.
**Indicators**: Future

**Q**: Using math to apply a pattern to what I saw
**R**: I will use it in *everyday life in med school* when thinking about medications, anesthesia and other factors.
**Indicators**: Future

**Q**: Working with the equipment
**R**: It helps build confidence in doing hands on things somewhat, but I don't think working with this specific equipment is really helpful for *me in the future*
**Indicators**: Future

After/Later

The utility of a practice after the course is over, without a specific future path or career indicator

- *I won't use this again/anymore*
- *This is the only time I will use this*

**Q**: Working with the equipment
**R**: I may *never see this equipment again*, and if i were to go to a lab the equipment and how it is used may be very different. learning the specifics of the equipment used *may not be helpful*, but it is valuable to understand what it does and why you would use it for the study
**Indicators**: After/later

## Interest

Indication of personal interest or preference for something

## Indicators

Enjoyable/interest
Preference

- Some discussion of like or dislike
  - Care/don't care
  - Want/don't want
- Requirements: Preference statements require an additional connection to a practice
  - *I like this thing because it helps me understand the purpose of the experiment*
  - The connection does not need to be fully concrete but it does need to be more concrete than abstract
    - *I like numbers because of how they work* x
    - *I like number because of how they work* ***to prove the concepts*** ✔️

Notable Feature

- Interest statements frequently contain a sentence structure like 'thought-1 **but** thought-2.'
- Statements like this are Interest statements when thought-1 contains a preference (like/hate/etc.).
- Generally in these cases thought-1 is a negative preference and thought-2 is a positive statement.

Note:

- Have not seen many examples of this in survey data
- Have not seen examples that connect LT and I

**Q**: Doing calculations with data
**R**: is important because *i like numbers* and how they work out to prove your concepts.
**Indicators**: Preference, appreciation

**Q**: Using math as a tool to explain and predict
**R**: I think it is helpful just because *I enjoy math* and <u>it makes it easier for me to understand things.</u>
**Indicators**: Preference, enjoyment

**Q**: Presenting what my results mean
**R**: *I am not really into physics* so I *could care less* if I present the data that I find <u>because most the time I don't even understand it.</u>
**Indicators**: Preference, could [not] care less

**Q**: Presenting what my results mean
**R**: *I don't love physics*, so *i don't love presenting* the work, **but** i<u>t is important</u> to receive peer feedback
**Indicators**: Preference, I don't love

---

## Negotiated Experience

Dealing with (or adapting to) the expectations and value of the experimental physics community. Negotiating how those values and expectations align (or not) with one's own

## Indicators

Tension in Expectations
Disagreement in the necessity or value of a practice that is emphasized in the course or in physics generally

- I don't want to do this but I do it because I have to
- Not as important, realistic, true, necessary
- Frustrating
- Student
  - The response is based around the fact that they are a student. *This isn't important because I'm only a student.*
  - Additional requirements to these statements
    - Statement about being a *student*
    - And a connecting <u>value statement</u>
    - ie: <u>This isn't important</u> because *I am only a student* and I just need to get through this
- Just a class
  - The value or lack of is based on the fact that it is just a class or lab
  - Additional requirements to these statements
    - Statement about it being a *class/lab*
    - And a connecting <u>value statement</u>
    - ie: <u>This isn't important</u> because *it is only a lab* and I just need to get through this

**Q**: Knowing how to adapt equipment to new situations
**R**: *As a student* I feel like this <u>is not as important</u> because most experiments I will do in a lab class will be controlled. This might be useful for the future but <u>as of now I don't think it is necessary</u>.
**Indicators**: Tension in expectation - student

**Q**: Presenting what my results mean

**R**: for us *in a lab like this*, we are all recreating the same experiments. While a lot of the time we get different results, we are all doing the same research and experiments. Due to this, it isn't the most important for us to convey our research.
**Indicators**: Tension in expectations - just a class

Valuing vs. seeing value

They can recognize the value of the practice, with respect to the physics community or the course, but they do not personally value it

- I understand the value in the course, but I don't think it is valuable to me personally
- (Ir)relevant, Inconsequential
    - This is important in physics but it is not relevant to me

**Q**: Presenting what my results mean
**R**: Typically, all of the results from DATA Lab experiments are **inconsequential in a larger physics picture**. *Maybe it is somewhat helpful in understanding the lab*, but it is not the most important part of an entire process **for students**.
**Note**: Here the combination of the bold statements make this fit into the 'just a class' code
**Indicators**: Tension in expectations - student/just a class, also value vs seeing value
**Explanation**: There is a lot going on in this statement, first wrt tension we have the the first bolded part with *"inconsequential*" and the underlined "*not the most important part*" both indicated a tension between the student's expectations and that of the course. The already mentioned part plus the italicized "*maybe it is somewhat helpful*" indicates the value vs seeing value, they see why it could be a helpful thing but it isn't what really matters to them

Obligation

They only care about this thing because they have to for the course.

- I feel obligated to do this, even though I don't think it matters so much
- Obligated, Forced/pushed, Need/had to
- Grade
    - Something done for a grade or something that is important because they are graded on it
    - Indicators:
        - Need this for a good grade
        - You won't get as good of a grade
        - It doesn't matter for the grade

**Q**: Using data to determine the significance of my results
**R**: It doesn't matter that much for me as long as I get the results. *That is what most of the points for a lot of classes are* [associated] with.
**Indicators**: Obligation - Grade

**Explanation**: We get obligation from two things here, the first is "*it doesn't matter … as long as I get the results*" and then they also show us that the value comes from the fact that they are graded on it "*that is what most of the points [are for]*"

**Q**: Using graphs to interpret results
**R**: However, I felt that sometimes *the "need" of graphs was a bit counter productive*. I felt like I was *forced into* creating a linear model of the data that we had taken, and that if I did not take data that could be graphed linearly then that data would be basically useless, *which is not always true*
**Indicators**: Obligation, Disagreement, tension in expectations
**Explanation**: We have a word that indicated obligation "forced" in addition to that we have two examples of tension

- Counter productive
- Not always true

**Q**: Interpreting graphs to understand relationships between parameters
**R**: Not important because *I don't like graphs* and *I feel obligated* to make one even when I don't understand the concepts very well
**Indicators**: Obligation, Tension in expectations, Preference against
**Explanation**: Another example of obligation, where they use that word specifically. There is also tension in both the fact that they do not like graphs and they do not understand the concepts.

Notable Feature

- These statements often have a structure of 'thought-1 but thought-2' where 1 and 2 are often contradictory
- It is only NE when the first thought is not an interest statement (I like this but...) **AND** the second thought is an NE statement (any of the above indicators)
- Often, thought-1 is positive and thought-2 is negative for NE, the opposite is true for Interest

**Q**: Communicating my results by answering specific questions
**R**: *It helps me* keep track of what I'm doing **but** sometimes the organization *demanded in class isn't realistic* for real life.
**Indicators**: Obligation, Tension in expectations
**Explanation**: Second half of the statement is Tension in Expectations

---

## Recognition

Receiving recognition for performing physics practices and showing competence in them

Notes:

- We have not seen examples of this in survey or interview responses
- We do not have examples of R combined with NE

---

## Community Membership

The value of the practice comes from the community

### Indicators

Distinction between multiple communities
Something is important in one community and not in another
- Science vs physics
- Class vs research lab

**Q**: Explaining how I did what I did
**R**: Because when performing an experiment of any sort you need to be detailed in order to be able to recreate the experiment exactly and reproduce the results. Or conversely to be able to go through and alter the procedure and check for flaws that could prohibit the results you hypothesize. This is *true in any science* and good practice even in physics.
**Note**: Lower confidence
**Indicators**: Science, Comes from community, distinction between communities
**Explanation**: We are triggered on "true in any science" as our indicator that they are talking about the science community. The first two sentences are the description/explanation but don't actually include any indicator for identity, that comes in the last sentence

---

## Competence

Perceived competence in practices valued in the community

Notes:
- We have struggled to find examples of competency statements in the survey data

---

## Other

I am not sure where these fit but there are still identity statements

## Indicators

Not an expert

**Q**: Communicating my results by answering specific questions
**R**: Not as helpful because I am *not a professional* and don't necessarily understand everything that the lab had to offer, just the major concepts.
**Indicators**: Not an expert

**Q**: Having help from my group if I have questions
**R**: I am *not a professional* and need a lot of help when conducting experiments so having others to lean on is helpful.
**Indicators**: Not an expert

Purpose

- The purpose of doing this

**Q**: Communicating my results by answering specific questions
**R**: Explaining findings is the *whole purpose of doing an experiment*
**Indicators**: Purpose

Relevance

- What I am doing is irrelevant/relevant
- It has been done before
- We know the answer
- What we're doing is relevant in some way

**Q**: Making connections to the bigger concepts
**R**: it helps me to put forth more effort if I can understand the concept in a *real life example*.
**Indicators**: Relevance

**Q**: Working with the equipment
**R**: Is not really important because I don't do many experiments or measurements in my *regular life*.
**Indicators**: Relevance

Utility

- Helps (or doesn't) me to
- To learn, understand, do something

**Q**: Using math as a tool to explain and predict

**R**: As an undergraduate student, sometimes the underlying concepts behind experiments go over my head. For me, it's sometimes *most useful for me* to relate a concept to an equation and understand how different variables in the equation relate to one another, rather than more complicated physical variables in an experiment.
**Indicators**: Utility

# APPENDIX E

# DEVELOPMENT OF PRACTICE QUESTIONS

This appendix provides a detailed examples of the process of producing the original questions for Version 1 of the survey from the interview results (see Sec. 6.2.1).

## E.1 Emergent Coding of Interviews

The interviews were coded for the different ways students interpreted the physics practices. The descriptions of the practices were used to create and code into specific sub-bins. Table E.1 shows three interview quotes describing understanding equipment and the associated emergant coding (the overview column). Table E.2 shows the sub-bins that were produced from analysis of all of the responses to the question about understanding equipment.

Table E.1: Review interviews for where students talk about specific practice, 1-3 word summary of their interpretation of the practice. The practice here is understanding equipment.

| Student | Statement | Overview |
|---|---|---|
| Beth | We used different solenoids, so like, do we want them really close together, do we want them far apart, how does that affect anything. We just kind of figured out what works best for us in the experiment. | Trying it out |
| Clara | Be familiar with what it is and how it's used, or like how it can be used because a lot of things can be used in different ways, um so, just being familiar with how it works, what it can do, what it can measure. | What is it, How is it used, Different ways it can be used, What it can measure |
| Alice | Just seeing even just how the equipment works. I know that oscilloscopes are just a whole bunch of buttons, two little screens, one of them is green with a whole bunch of lines on it and you know its just, when you see that light going across in that pattern, it's i don't know, I just think it's cool. | How the equipment works What it allows you to do/see |

## E.2 Coding and Summarizing

Once the common sub-bins were defined the student quotes were sorted into the associated bins. The quotes were reduced to the main point. For example, Clara's description can be simplified into 'knowing how the equipment works' (Table E.3).

Table E.2: Summaries turned into common sub-bins

| Sub-bins | Description |
|---|---|
| Adapting | Knowing how to fit the equipment into new systems, or how to use it in different situations or to measure different things |
| Exploring | Exploring the equipment, trying things, fiddling with things, seeing how adjustments change things |
| How it works | Knowing how the equipment works |
| How to use it | Knowing how to use it to get what you need |
| Limitations | What are the limitations of the equipment, what can't you do/measure with it |
| Purpose | What purpose does it serve in this experiment, what does sit let you do/see, What does it measure, what are the different ways it can be used |

Table E.3: Student responses sorted into bins and summarized

| **Sub-bin: How it works** | Alice | Clara |
|---|---|---|
| **Overall summary of each interpretation** | Understanding how it works, seeing how it works | Familiar with how the equipment works |
| **Main points** | How it works<br>Seeing how it works | How it works |

## E.3 Representative Examples

After the coding was completed examples were created that were representative of the different student responses that fell into that sub-bin (Table E.4).

Table E.4: Statements that reflect all of the 'How it works' examples

| |
|---|
| See how the equipment works |
| Know how the equipment works |
| Know how the parts work |
| Know how the equipment works to adapt it to your needs |

# APPENDIX F

# STATISTICS

In this appendix the statistics used in this dissertation are described. These tests were used in Chapter 6.

## F.1 Significance Testing

In analzing survey data there is a challenge in generalizing the results from a sample to the broader population. In most of our work we have been sampling the students in the DATA Lab, in hopes of generalizing the broader population of students in physics labs.

### F.1.1 $\chi^2$ Contingency Table Analysis

The main means of significance testing we did in this work was $\chi^2$ contingency table analysis of the distributions of responses to the survey questions. This is a way to determine if there is a statistically significant difference between two sets of data, or the responses to two different questions in our case. The formula to determine $\chi^2$.

$$\chi^2 = \sum \frac{(\text{observed} - \text{expected})^2}{\text{expected}} \tag{F.1}$$

Here, observed in equation F.1 refers to eq. F.2, which comes from the data that have been collected.

$$E_{ij} = \frac{(\text{sum of row } j)(\text{sum of col } i)}{\text{sample size}} \tag{F.2}$$

$$\text{Observed} = \begin{bmatrix} E_{11} & E_{21} \\ E_{12} & E_{22} \end{bmatrix} \tag{F.3}$$

Expected in F.1 refers to

$$E'_{ij} = \frac{(\text{sum of row } j)(\text{sum of col } i)}{\sum E_{ij}}. \tag{F.4}$$

Using F.2 and F.2, $\chi^2$ becomes

$$\chi^2 = \frac{\left(E_{ij} - E'_{ij}\right)^2}{E'_{ij}}. \tag{F.5}$$

This can be illustrated with an example from the data. Say we want to determine whether or not the responses to two practice questions are similar enough to collapse into one question. The distributions to both questions are in Table F.1.

Table F.1: Observed distributions of responses to two practice questions.

| | Practice 1 | Practice 2 |
|---|---|---|
| Agree | 80 | 100 |
| Nuteral | 25 | 18 |
| Disagree | 50 | 30 |

We can calculated the expected responses using equation F.4. The expected table becomes,

Table F.2: Expected distributions of responses to two practice questions

| | Practice 1 | Practice 2 |
|---|---|---|
| Agree | 92 | 88 |
| Nuteral | 22 | 21 |
| Disagree | 41 | 39 |

Using we can calculate $\chi^2$ for this sample.

$$\chi^2 = 1.6$$

degrees of freedom, $df = 2$

Once $\chi^2$ is calculated for the observations the p-value can be determined. The p-value is the probability that the data would be at least as extreme as the observation, it is used to determine whether or not to accept the null hypothesis. In this case the null hypothesis is that the two distributions are the same. With $\chi^2$ and the degrees of freedom (rows − 1)(cols − 1) the p-value can be determined from a table. Before that happens though it is important to correct the p-value that determines significance for the number of tests, the Bonferrinu Correction[1] (Sec. F.1.2). In this example there was only one test so we can refer to the table, for $df = 2$ the value of $\chi^2 = 1.6$ is smaller than what is presented in the table, meaning our p-value > 0.1 and we must accept the null hypothersis that these two samples are the same.

Table F.3: $\chi^2$ Table

| df | p = 0.1 | 0.05 | 0.01 |
|---|---|---|---|
| 1 | 2.706 | 3.841 | 6.635 |
| 2 | 4.605 | 5.991 | 9.210 |
| 3 | 6.521 | 7.815 | 11.345 |

### F.1.2 Bonferroni Correction

When multiple statistical tests are completed on the same sample it is easy to keep reproducing an error, so it is important to maintian stricter criteria. Instead of taking a p-value of 0.05 as significant a correction is necessary:

$$\text{Corrected p-value} = \frac{\text{(p-value of significance, 0.05)}}{\text{number of tests}}. \tag{F.6}$$

In pairwise testing the number of tests can be determined by the formula below, where $n$ = the number of individual sources in the sample,

$$\text{Number of tests} = \sum n - 1. \tag{F.7}$$

This can again be illustrated with an example from the data. In the analysis for Version 3 of the survey we compared all of the communicating questions against eachother in pairwise testing, a total of 8 questions.

[1]Bonferroni, C. E. "Il calcolo delle assicurazioni su gruppi di teste." In Studi in Onore del Professore Salvatore Ortu Carboni. Rome: Italy, pp. 13-60, 1935.

$$n = 8$$

$$\text{Number of tests} = \sum n - 1 = \sum 7 = 28$$

$$\text{Corrected p-value} = \frac{(\ 0.05)}{\text{number of tests}} = \frac{0.05}{28} = 0.002$$

Our new p-value of significance is 0.002.

### F.1.3 Effect Size

The p-value and $\chi^2$ are not sufficient to determine how reasonable it is to accept or reject the null hypothesis. The p-value tells you whether or not the two samples are different but not how different they are. It is necessary to also calculated the size of the difference between the two groups, or the effect size. The effect size used here is called Cramér's V:

$$V = \sqrt{\frac{\chi^2/n}{\min(k-1, r-1)}}, \tag{F.8}$$

Where $k$ = number of columns $r$ = number of rows $n$ = number of observations. The size of the effect as calculated depends on the dimensions of the sample,

$$df^* = \min(\text{rows} - 1, \text{cols} - 1) \tag{F.9}$$

$$\begin{array}{cccc} & \text{small} & \text{medium} & \text{large} \\ df^* = 1 & 0.1 & 0.3 & 0.5 \\ df^* = 2 & 0.07 & 0.21 & 0.35 \\ df^* = 3 & 0.06 & 0.17 & 0.29 \end{array} \tag{F.10}$$

## F.2 Inter Rater Reliabiliy - Cohen's $\kappa$

In qualitative studies it is common to bring in an outside researcher to help determine the reliability of the work doone by the original researcher. For example, in Chapter 4 we describe the coding of the identity responses. In order to verify the reliability of the codebook and the coding done but the original researcher we brought in an external researcher to code a subset of responses. It is important to quantify the inter rater reliability, we use Cohen's $\kappa$ to do this. The equation to calculate Cohen's $\kappa$ is

$$\kappa \equiv \frac{p_o - p_e}{1 - p_e}, \tag{F.11}$$

where $p_e$ is defined as

$$p_e = \frac{1}{N^2} \sum_k n_{k1} n'_{k2} \tag{F.12}$$

with $n_{ki}$ = Number of times rater $i$ picked catagory $k$. $p_o$ is defined by

$$p_o = \frac{N_{\text{agree}}}{N_{\text{total}}}, \tag{F.13}$$

This can be illustrated by an example from our analysis.

Table F.4: How each researcher coded the set of responses into the five different categories.

| Code | Internal Researcher | External Researcher |
|---|---|---|
| LT | 1 | 2 |
| Interest | 6 | 7 |
| CM | 6 | 6 |
| NE | 11 | 9 |
| Other | 9 | 9 |
| Total | 33 | 33 |

There are 5 possible categories $k = 5$ and 33 items $N_{\text{total}} = 33$

Table F.5: $n_{k1} n_{k2}$ for each category.

| | LT | Interest | CM | NE | Other |
|---|---|---|---|---|---|
| $n_{k1} n_{k2}$ | 2 | 42 | 36 | 99 | 81 |

$$p_e = \frac{1}{N^2} \sum_k n_{k1} n_{k2} = \frac{260}{33^2} = 0.24 \tag{F.14}$$

$$p_o = \frac{N_{\text{agree}}}{N_{\text{total}}} = \frac{31}{33} = 0.94 \tag{F.15}$$

$$\kappa \equiv \frac{p_o - p_e}{1 - p_e} = \frac{0.94 - 0.24}{1 - 0.24} = 0.92 \tag{F.16}$$

Our results is $\kappa = 0.92$ and a $\kappa$ between 0.81-1.0 almost perfect agreement [84].

## APPENDIX G

## SURVEY QUESTIONS REFERENCE TABLE

## G.1 Table of Survey Questions

Reference table of every survey question, whether it was kept or removed at each step and the reason for removal. Specific questions are referenced in Chapter 6.

Table G.1: Survey questions from every version and the reason for removal.

| Reference | Question | Version 2 | Version 3 | Version 4 | Reason for Removal |
|---|---|---|---|---|---|
| | | | **Communicating** | | |
| C1 | Explaining what I found is important | x | x | x | x |
| C2 | Explaining what I was trying to do is important | x | x | Removed | Statistically and visually similar distributions |
| C3 | Explaining what it means is important | Removed | - | - | Too vague |
| C4 | Explaining my results is important | x | Removed | - | Similar distributions |
| C5 | Explaining my interpretation of the results is important | x | Removed | - | Similar distributions |
| C6 | Communicating my results by answering specific questions is helpful | x | Removed | - | Similar distributions |
| C7 | Presenting what my results mean is important | x | Removed | - | Similar distributions |
| C8 | Presenting what I did is important | x | x | x | x |
| C9 | Communicating my results by writing in my lab notebook is helpful | x | x | x | x |
| C10 | Communicating my results by writing up a conclusion is helpful | x | x | Removed | Statistically and visually similar distributions |
| C11 | Communicating my results with data tables graphs and pictures is important | Removed | - | - | Was not accomplishing intended goal |

## Table G.1 (cont'd)

| Reference | Question | Version 2 | Version 3 | Version 4 | Reason for Removal |
|---|---|---|---|---|---|
| C12 | Being able to communicate my understanding is important | x | x | x | x |
| C13 | Explaining what I did is important | x | x | Removed | Statistically and visually similar distributions |
| C14 | Explaining why I did what I did is important | x | Removed | - | Similar distributions |
| C15 | Explaining how I did what I did is important | x | Removed | - | Similar distributions |
| C16 | Explaining what my results mean is important | x | x | Removed | Statistically and visually similar distributions |
| C17 | Communicating my results with confidence is important | Removed | - | - | Misinterpreting confidence |
| C18 | Using uncertainty to express the confidence in my results is helpful | x | x | x | x |
| **Data Analysis** | | | | | |
| DA1 | Comparing my results to the expected is important | x | x | x | x |
| DA2 | Determining if my data matches what I expected is important | Removed | - | - | No examples of identity |
| DA3 | Making connections to the bigger concepts is valuable | x | x | Removed | Covered by other questions in the practice group |
| DA4 | Using the concepts to make my data into something I can interpret is important | x | Removed | - | Similar distributions |
| DA5 | Using graphs to interpret results is important | x | x | Removed | Statistically similar distributions |
| DA6 | Making graphs from collected data is helpful | x | x | x | x |
| DA7 | Interpreting graphs to understand relationships between parameters is important | x | x | Removed | Statistically and visually similar distributions |
| DA8 | Doing calculations with data is important | x | x | - | Mistakenly dropped from 1 to 2 |
| DA9 | Doing math with my data in order to get my results is important | x | x | Removed | Statistically and visually similar distributions |

**Table G.1 (cont'd)**

| Reference | Question | Version 2 | Version 3 | Version 4 | Reason for Removal |
|---|---|---|---|---|---|
| DA10 | Using math as a tool to explain and predict is helpful | x | x | x | x |
| DA11 | Looking for trends in my data is important | Removed | - | - | No examples of identity |
| DA12 | Using math to apply a pattern to what I saw is valuable | x | Removed | - | Similar distributions |
| DA13 | Calculating the average value for each variable tested/measured is important | x | Removed | - | "They usually disagree with it because it is not actually an expert practice it is not providing useful information" |
| DA14 | Using data to determine the significance of my results is important | x | Removed | - | Significance could be misinterpreted |
| DA15 | Observing trends and patterns in the experiment and applying equations to that is important | x | Removed | - | Similar distributions |
| DA16 | Determining patterns from my data is important | x | x | x | x |
| DA17 | Looking for trends or asking why something happened mathematically is important | x | Removed | - | Similar questions |
| DA18 | Testing the validity of my results with uncertainty is important | x | Removed | - | Similar distributions |
| DA19 | Expressing confidence in my results with uncertainty is important | x | Removed | - | Nearly the same as a communicating question |
| **Executing Experiments** | | | | | |
| EE1 | Doing calculations is helpful | Removed | - | - | Too vague |
| EE2 | Working with the equipment is valuable | x | x | x | x |
| EE3 | Collecting data and taking measurements is important | x | x | x | x |
| EE4 | The fact that uncertainty means measurements may be off inaccurate or wrong is important | x | Removed | - | Similar distributions |

## Table G.1 (cont'd)

| Reference | Question | Version 2 | Version 3 | Version 4 | Reason for Removal |
|---|---|---|---|---|---|
| EE5 | Knowing that the uncertainty my have an impact on the experiment is important | x | x | Removed | Statistically and visually similar distributions |
| EE6 | Knowing that there is uncertainty associated with our measurements is important | x | Removed | - | Similar distributions |
| EE7 | Working to minimize the uncertainty in my experiment is important | x | x | x | x |
| | **Group Work** | | | | |
| GW1 | Caring about how each member of my group sees my work/effort is important | x | x | - | Mistakenly dropped from 1 to 2 |
| GW2 | Being accountable to my group is valuable | Removed | - | - | No examples of identity |
| GW3 | Figuring out how to communicate with my group is important | x | Removed | - | Similar questions |
| GW4 | Figuring out how to work with my group is important | Removed | - | - | Disregarding 'figuring out' |
| GW5 | Communicating with my group about the results is important | x | x | Removed | Statistically and visually similar distributions |
| GW6 | Communicating with my group about how to do things is important | x | Removed | - | Similar distributions |
| GW7 | Communicating with my group about how things work is important | x | Removed | - | Similar distributions |
| GW8 | Talking things out with my group is helpful | Removed | - | - | Answered 'yes and no' a lot |
| GW9 | Everyone feeling comfortable sharing their ideas in their group is important | x | x | x | x |
| GW10 | Everyone in the group contributing an equal amount is important | x | x | - | Mistakenly dropped from 1 to 2 |
| GW11 | Giving everyone in the group a chance to contribute is important | x | x | Removed | Statistically similar distributions |

## Table G.1 (cont'd)

| Reference | Question | Version 2 | Version 3 | Version 4 | Reason for Removal |
|---|---|---|---|---|---|
| GW12 | Everyone in the group agreeing on the goal is important | Removed | - | - | No examples of identity |
| GW13 | Following one group member's interpretation of the goal is important | Removed | - | - | No examples of identity |
| GW14 | Having help from my group to check my work is important | x | Removed | - | Similar distributions |
| GW15 | Having help from my group if I have questions is important | x | x | x | x |
| GW16 | Bringing many ideas together in a group is important | x | Removed | - | Similar distributions |
| GW17 | Bouncing ideas off of my group members is important | x | x | x | x |
| GW18 | Working in a group is important | Removed | - | - | - |
| GW19 | Working together as a group is important | x | Removed | - | Similar questions |
| GW20 | Making decisions together as a group is important | x | x | x | x |
| GW21 | Letting each group member have hands-on time with the equipment is important | x | Removed | - | Similar distributions |
| GW22 | Agreeing as a group on how to complete a task before moving forward is important | x | Removed | - | Not an important practice reflected in free-response statements also ambiguous in what a preferred response would be |
| GW23 | Everyone in the group doing their own thing is important | Removed | - | - | No examples of identity |
| GW24 | Making decisions for the group by myself is important | Removed | - | - | No examples of identity |
| GW25 | Valuing every group member's ideas is important | x | x | Removed | Statistically and visually similar distributions |
| | **Planning Experiments** | | | | |
| PE1 | Having a plan to answer my questions is important | x | x | Removed | Statistically and visually similar distributions |
| PE2 | Having a plan to get to my goal is important | x | Removed | - | Similar distributions |

**Table G.1 (cont'd)**

| Reference | Question | Version 2 | Version 3 | Version 4 | Reason for Removal |
|---|---|---|---|---|---|
| PE3 | Knowing what equipment I need for the experiment I am planning is important | x | x | Removed | Statistically and visually similar distributions |
| PE4 | Knowing what design works best for the experiment I am planning is important | x | x | x | x |
| PE5 | Having a procedure when designing an experiment is important | x | x | Removed | Statistically and visually similar distributions |
| PE6 | Creating a procedure when designing an experiment is important | Removed | - | - | No examples of identity |
| PE7 | Planning out the steps when designing an experiment is important | Removed | - | - | No examples of identity |
| PE8 | Figuring out how to get the information I need when desiging an experiment is important | x | x | Removed | Statistically and visually similar distributions |
| PE9 | Figuring out how to set up the equipment when planning an experiment is important | x | x | x | x |
| PE10 | Figuring out how to get the equipment and measurement devices into the system when designing an experiment is important | Removed | - | - | Some confusion on wording and some misinterpretation |
| PE11 | Having an hypothesis when planning an experiment is important | x | x | x | x |
| PE12 | Knowing what my goal is when planning an experiment is important | x | x | Removed | Statistically and visually similar distributions |
| PE13 | Knowing what I am trying to find out is important | Removed | - | - | No examples of identity |
| PE14 | Knowing how to get to my goal when planning an experiment is important | x | Removed | - | Similar questions |
| | **Understanding Equipment** | | | | |

## Table G.1 (cont'd)

| Reference | Question | Version 2 | Version 3 | Version 4 | Reason for Removal |
|---|---|---|---|---|---|
| UE1 | Knowing that the equipment may have multiple uses is important | x | x | x | x |
| UE2 | Knowing how to adapt equipment to new situations is useful | x | x | x | x |
| UE3 | Trying out the equipment and seeing what it does is valuable | x | x | Removed | Covered by other questions in the practice group |
| UE4 | Tinkering with the equipment is useful | x | Removed | - | Similar questions |
| UE5 | Seeing how changing one component of the equipment affects something else is useful | x | x | Removed | Statistically and visually similar distributions |
| UE6 | Figuring out how the equipment works best for me is important | Removed | - | - | Not an ideal question for intro students, No examples of identity |
| UE7 | Identifying the extreme settings of the equipment is important | x | x | Removed | Covered by other questions in the practice group |
| UE8 | Testing the tolerance of the equipment is important | Removed | - | - | Tolerance is too jargony, No examples of identity |
| UE9 | Seeing how the equipment works is helpful | Removed | - | - | Too vague, a lot of varity in responses No examples of identity |
| UE10 | Knowing how the equipment works is important | x | x | x | x |
| UE11 | Knowing what the equipment is designed to measure is valuable | x | x | Removed | Statistically and visually similar distributions |
| UE12 | Knowing how the parts of the equipment work is valuable | x | Removed | - | Similar distributions |
| UE13 | Knowing how to use the equipment is important | Removed | - | - | A lot on correct/accurate experiments/results, No examples of identity |
| UE14 | Knowing how to get what I need from the equipment is important | x | Removed | - | Similar distributions |
| UE15 | Knowing how to turn the equipment on and plug it in is important | Removed | - | - | No examples of identity |

**Table G.1 (cont'd)**

| Reference | Question | Version 2 | Version 3 | Version 4 | Reason for Removal |
|---|---|---|---|---|---|
| UE16 | Figuring out how I want to use it the equipment is important | Removed | - | - | A lot of people seem to interpret this as 'figuring out how to use the equipment' and ignoring the 'I want' part |
| UE17 | Making the equipment measure something it was not originally intended for is important | x | Removed | - | Most people disagree with this because it is not a common practice in lab classes so this question is not useful |
| UE18 | Knowing what not to do with the equipment is useful | x | Removed | - | Similar distributions |
| UE19 | Knowing the limits/capabilities of the equipment is useful | x | x | x | x |
| UE20 | Understanding the limitations of the measurements the equipment can make is important | Removed | - | - | Not everyone is connecting this to uncertainty, No examples of identity |
| UE21 | Understanding the limited precision of an apparatus is important | Removed | - | - | Apparatus is too jargony, No examples of identity |
| UE22 | Knowing what the equipment is used for is important | Removed | - | - | No examples of identity |
| UE23 | Knowing how the equipment can be used is important | Removed | - | - | No examples of identity |
| UE24 | Knowing what the equipment can do/measure is important | Removed | - | - | No examples of identity |
| UE25 | Knowing how to fix the equipment when it is broken is useful | x | x | x | x |

## APPENDIX H

## SURVEY VERSION 1

This appendix has the entire survey from Version 1 (Sec. 6.3). This is how it would have been viewed by each student on Qualtrics[1]. For each practice each student saw a random question from the question group. Each item is idicated by:

'Practice Abbriviation' + 'Question Name' + 'Question Group'

A group work item for example looks like:

GW + Help 1 + Q1

That is a group work question (the question name is irrelavant) in the first group. Each student saw one group work question in question group one. See Chapter 6 Sec. 6.3 for details on this version of the survey.

[1]Qualtrics, 2019, Qualtrics Labs, Inc. Provo, UT, USA

about your role and rights as a research participant, would like to obtain information or offer input, or would like to register a complaint about this study, you may contact, anonymously if you wish, the Michigan State University's Human Research Protection Program at 517-355-2180, Fax 517-432-4503, or e-mail irb@msu.edu or regular mail at Olds Hall, 408 West Circle Drive #207, MSU, East Lansing, MI 48824.

9. DOCUMENTATION OF INFORMED CONSENT.

Your affirmations below means that you voluntarily agree to participate in this research study.

Do you agree to participate in the study?
An answer is required to receive extra credit in your course.
(If you choose 'No' you will be redirected to the end of the survey)

Yes

No

**Intro Block**

What physics class(es) are you in currently?

What is your current major?

Why did you choose to major in science?

What is your interest in physics?

Very low

Low

Moderate
High
Very high

What are your future plans?

**Community Block**

As an undergraduate student at Michigan State University taking science classes you are part of many different communities. These communities may influence your perspective as you go through your undergraduate career. Below we have some examples of communities that may be relevant to you, please choose all that apply and add on if we are missing something.

Choose all that apply

Science student
Person in my major
A person with a future in ${q://QID4/ChoiceGroup/SelectedChoices}
An aware citizen
Curious person
Other:

PLEASE READ BEFORE PROCEEDING

The rest of the questions are focused on your experience in physics labs. A series of four questions will be addressing the same idea. **There are no wrong answers**, we are just looking for your opinion on these things. We are trying to understand your reasoning, so it is **important that you answer the free-response questions** as well as the multiple-choice ones. Even if your reasoning seems obvious to you it may not be clear to us.

This will look like:
Do YOU agree/disagree with this statement?
Would an EXPERIMENTAL PHYSICIST agree/disagree with this statement?

Explain why YOU agree/disagree with the statement
Explain why you think an EXPERIMENTAL PHYSICIST would agree/disagree with this statement

**GW NA 1 Q2 - Apr 19, 2018**

Working in a group is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, working in a group is important (not important) because...

For an EXPERIMENTAL PHYSICIST, working in a group is important (not important) because...

**GW Adapt 1 Q2 - Apr 19, 2018**

Figuring out how to communicate with my group is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, figuring out how to communicate with my group is important (not important) because...

For an EXPERIMENTAL PHYSICIST, figuring out how to communicate with my group is important (not important) because...

**GW Accountable 1 Q2 - Apr 19, 2018**

Caring about how each member of my group sees my work/effort is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, caring about how each member of my group sees my work/effort is important (not important) because...

For an EXPERIMENTAL PHYSICIST, caring about how each member of my group sees my work/effort is important (not important) because...

**GW Accountable 2 Q2 - Apr 19, 2018**

Being accountable to my group is valuable

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, being accountable to my group is valuable (not valuable) because...

For an EXPERIMENTAL PHYSICIST, being accountable to my group is valuable (not valuable) because...

**GW Help 1 Q2 - Apr 19, 2018**

Having help from my group to check my work is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, having help from my group to check my work is important (not important) because...

For an EXPERIMENTAL PHYSICIST, having help from my group to check my work is important (not important) because...

**GW Help 2 Q2 - Apr 19, 2018**

Having help from my group if I have questions is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, having help from my group if I have questions is important (not important) because...

For an EXPERIMENTAL PHYSICIST, having help from my group if I have questions is important (not important) because...

**GW Goal 1 Q2 - Apr 19, 2018**

Everyone in the group agreeing on the goal is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | ○ | ○ | ○ | ○ | ○ |
| What would an EXPERIMENTAL PHYSICIST say about their research | ○ | ○ | ○ | ○ | ○ |

For ME, everyone in the group agreeing on the goal is important (not important) because...

For an EXPERIMENTAL PHYSICIST, everyone in the group agreeing on the goal is important (not important) because...

**GW Goal 2 Q2 - Apr 19, 2018**

Following one group member's interpretation of the goal is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | ○ | ○ | ○ | ○ | ○ |
| What would an EXPERIMENTAL PHYSICIST say about their research | ○ | ○ | ○ | ○ | ○ |

For ME, following one group member's interpretation of the goal is important (not important) because...

For an EXPERIMENTAL PHYSICIST, following one group member's interpretation of the goal is important (not important) because...

**GW Together 1 Q2 - Apr 19, 2018**

Working together as a group is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, working together as a group is important (not important) because...

For an EXPERIMENTAL PHYSICIST, working together as a group is important (not important) because...

**GW Together 2 Q2 - Apr 19, 2018**

Making decisions together as a group is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, making decisions together as a group is important (not important) because...

For an EXPERIMENTAL PHYSICIST, making decisions together as a group is important (not important) because...

**GW Adapt 2 Q2 - Apr 19, 2018**

Figuring out how to work with my group is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, figuring out how to work with my group is important (not important) because...

For an EXPERIMENTAL PHYSICIST, figuring out how to work with my group is important (not important) because...

**GW Ideas 1 Q1 - Apr 19, 2018**

Bringing many ideas together in a group is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, bringing many ideas together in a group is important (not important) because...

For an EXPERIMENTAL PHYSICIST, bringing many ideas together in a group is important (not important) because...

**GW Ideas 2 Q1 - Apr 19, 2018**

Bouncing ideas off of my group members is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | ○ | ○ | ○ | ○ | ○ |
| What would an EXPERIMENTAL PHYSICIST say about their research | ○ | ○ | ○ | ○ | ○ |

For ME, bouncing ideas off of my group members is important (not important) because...

For an EXPERIMENTAL PHYSICIST, bouncing ideas off of my group members is important (not important) because...

**GW Communication 1 Q1 - Apr 19, 2018**

Communicating with my group about the results is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, communicating with my group about the results is important (not important) because...

For an EXPERIMENTAL PHYSICIST, communicating with my group about the results is important (not important) because...

**GW Communication 2 Q1 - Apr 19, 2018**

Communicating with my group about how to do things is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, communicating with my group about how to do things is important (not important) because...

For an EXPERIMENTAL PHYSICIST, communicating with my group about how to do things is important (not important) because...

**GW Communication 3 Q1 - Apr 19, 2018**

Communicating with my group about how things work is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | ○ | ○ | ○ | ○ | ○ |
| What would an EXPERIMENTAL PHYSICIST say about their research | ○ | ○ | ○ | ○ | ○ |

For ME, communicating with my group about how things work is important (not important) because...

For an EXPERIMENTAL PHYSICIST, communicating with my group about how things work is important (not important) because...

**GW Communication 4 Q1 - Apr 19, 2018**

Talking things out with my group is helpful

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | ○ | ○ | ○ | ○ | ○ |

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, talking things out with my group is helpful (not helpful) because...

For an EXPERIMENTAL PHYSICIST, talking things out with my group is helpful (not helpful) because...

**GW Communication 5 Q1 - Apr 19, 2018**

Everyone feeling comfortable sharing their ideas in their group is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, everyone feeling comfortable sharing their ideas in their group is important (not important) because...

For an EXPERIMENTAL PHYSICIST, everyone feeling comfortable sharing their ideas in their group is important (not important) because...

**GW Together 3 Q1 - Apr 19, 2018**

Letting each group member have hands-on time with the equipment is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, letting each group member have hands-on time with the equipment is important (not important) because...

For an EXPERIMENTAL PHYSICIST, letting each group member have hands-on time with the equipment is important (not important) because...

**GW Together 4 Q1 - Apr 19, 2018**

Agreeing as a group on how to complete a task before moving forward is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, agreeing as a group on how to complete a task before moving forward is important (not important) because...

For an EXPERIMENTAL PHYSICIST, agreeing as a group on how to complete a task before moving forward is important (not important) because...

**GW Together 5 Q1 - Apr 19, 2018**

Everyone in the group doing their own thing is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, everyone in the group doing their own thing is important (not important) because...

For an EXPERIMENTAL PHYSICIST, everyone in the group doing their own thing is important (not important) because...

**GW Together 6 Q1 - Apr 19, 2018**

Making decisions for the group by myself is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, making decisions for the group by myself is important (not important) because...

For an EXPERIMENTAL PHYSICIST, making decisions for the group by myself is important (not important) because...

**GW Together 7 Q1 - Apr 19, 2018**

Valuing every group member's ideas is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | ○ | ○ | ○ | ○ | ○ |
| What would an EXPERIMENTAL PHYSICIST say about their research | ○ | ○ | ○ | ○ | ○ |

For ME, valuing every group member's ideas is important (not important) because...

For an EXPERIMENTAL PHYSICIST, valuing every group member's ideas is important (not important) because...

**GW Contribution 1 Q1 - Apr 19, 2018**

Everyone in the group contributing an equal amount is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | ○ | ○ | ○ | ○ | ○ |

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, everyone in the group contributing an equal amount is important (not important) because...

For an EXPERIMENTAL PHYSICIST, everyone in the group contributing an equal amount is important (not important) because...

**GW Contribution 2 Q1 - Apr 19, 2018**

Giving everyone in the group a chance to contribute is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, giving everyone in the group a chance to contribute is important (not important) because...

For an EXPERIMENTAL PHYSICIST, giving everyone in the group a chance to contribute is important (not important) because...

**UE How it works 1 Q1 - Apr 19, 2018**

Seeing how the equipment works is helpful

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, seeing how the equipment works is helpful (not helpful) because...

For an EXPERIMENTAL PHYSICIST, seeing how the equipment works is helpful (not helpful) because...

**UE How it works 2 Q1 - Apr 19, 2018**

Knowing how the equipment works is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, knowing how the equipment works is important (not important) because...

For an EXPERIMENTAL PHYSICIST, knowing how the equipment works is important (not important) because...

**UE How it works 3 Q1 - Apr 19, 2018**

Knowing what the equipment is designed to measure is valuable

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, knowing what the equipment is designed to measure is valuable (not valuable) because...

For an EXPERIMENTAL PHYSICIST, knowing what the equipment is designed to measure is valuable (not valuable) because...

**UE How it works 4 Q1 - Apr 19, 2018**

knowing how the parts of the equipment work is valuable

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, knowing how the parts of the equipment work is valuable (not valuable) because...

For an EXPERIMENTAL PHYSICIST, knowing how the parts of the equipment work is valuable (not valuable) because...

**UE How to use it 1 Q1 - Apr 19, 2018**

Knowing how to use the equipment is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | ○ | ○ | ○ | ○ | ○ |
| What would an EXPERIMENTAL PHYSICIST say about their research | ○ | ○ | ○ | ○ | ○ |

For ME, knowing how to use the equipment is important (not important) because...

For an EXPERIMENTAL PHYSICIST, knowing how to use the equipment is important (not important) because...

**UE How to use it 2 Q1 - Apr 19, 2018**

Knowing how to get what I need from the equipment is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | ○ | ○ | ○ | ○ | ○ |

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, knowing how to get what I need from the equipment is important (not important) because...

For an EXPERIMENTAL PHYSICIST, knowing how to get what I need from the equipment is important (not important) because...

**UE How to use it 3 Q1 - Apr 19, 2018**

Knowing how to turn the equipment on and plug it in is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, knowing how to turn the equipment on and plug it in is important (not important) because...

For an EXPERIMENTAL PHYSICIST, knowing how to turn the equipment on and plug it in is important (not important) because...

**UE Exploring 1 Q1 - Apr 19, 2018**

Trying out the equipment and seeing what it does is valuable

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, trying out the equipment and seeing what it does is valuable (not valuable) because...

For an EXPERIMENTAL PHYSICIST, trying out the equipment and seeing what it does is valuable (not valuable) because...

**UE Exploring 2 Q1 - Apr 19, 2018**

Tinkering with the equipment is useful

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, tinkering with the equipment is useful (not useful) because...

For an EXPERIMENTAL PHYSICIST, tinkering with the equipment is useful (not useful) because...

**UE Exploring 3 Q1 - Apr 19, 2018**

Seeing how changing one component of the equipment affects something else is useful

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, seeing how changing one component of the equipment affects something else is useful (not useful) because...

For an EXPERIMENTAL PHYSICIST, seeing how changing one component of the equipment affects something else is useful (not useful) because...

**UE Purpose 1 Q1 - Apr 19, 2018**

Knowing what the equipment is used for is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, knowing what the equipment is used for is important (not important) because...

For an EXPERIMENTAL PHYSICIST, knowing what the equipment is used for is important (not important) because...

**UE Purpose 2 Q1 - Apr 19, 2018**

Knowing how the equipment can be used is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, knowing how the equipment can be used is important (not important) because...

For an EXPERIMENTAL PHYSICIST, knowing how the equipment can be used is important (not important) because...

**UE Purpose 3 Q1 - Apr 19, 2018**

Knowing what the equipment can do/measure is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, knowing what the equipment can do/measure is important (not important) because...

For an EXPERIMENTAL PHYSICIST, knowing what the equipment can do/measure is important (not important) because...

**UE How to use it 4 Q2 - Apr 19, 2018**

Figuring out how I want to use it the equipment is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, figuring out how I want to use it the equipment is important (not important) because...

For an EXPERIMENTAL PHYSICIST, figuring out how I want to use it the equipment is important (not important) because...

**UE How to use it 5 Q2 - Apr 19, 2018**

Making the equipment measure something it was not originally intended for is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, making the equipment measure something it was not originally intended for is important (not important) because...

For an EXPERIMENTAL PHYSICIST, making the equipment measure something it was not originally intended for is important (not important) because...

**UE Exploring 4 Q2 - Apr 19, 2018**

Figuring out how the equipment works best for me is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, figuring out how the equipment works best for me is important (not important) because...

For an EXPERIMENTAL PHYSICIST, figuring out how the equipment works best for me is important (not important) because...

**UE Exploring 5 Q2 - Apr 19, 2018**

Identifying the extreme settings of the equipment is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, identifying the extreme settings of the equipment is important (not important) because...

For an EXPERIMENTAL PHYSICIST, identifying the extreme settings of the equipment is important (not important) because...

**UE Exploring 6 Q2 - Apr 19, 2018**

Testing the tolerance of the equipment is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, testing the tolerance of the equipment is important (not important) because...

For an EXPERIMENTAL PHYSICIST, testing the tolerance of the equipment is important (not important) because...

**UE Limitations 1 Q2 - Apr 19, 2018**

Knowing what not to do with the equipment is useful

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, knowing what not to do with the equipment is useful (not useful) because...

For an EXPERIMENTAL PHYSICIST, knowing what not to do with the equipment is useful (not useful) because...

**UE Limitations 2 Q2 - Apr 19, 2018**

Knowing the limits/capabilities of the equipment is useful

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, knowing the limits/capabilities of the equipment is useful (not useful) because...

For an EXPERIMENTAL PHYSICIST, knowing the limits/capabilities of the equipment is useful (not useful) because...

**UE Limitations 3 Q2 - Apr 19, 2018**

Understanding the limitations of the measurements the equipment can make is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, understanding the limitations of the measurements the equipment can make is important (not important) because...

For an EXPERIMENTAL PHYSICIST, understanding the limitations of the measurements the equipment can make is important (not important) because...

**UE Limitations 4 Q2 - Apr 19, 2018**

Understanding the limited precision of an apparatus is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, understanding the limited precision of an apparatus is important (not important) because...

For an EXPERIMENTAL PHYSICIST, understanding the limited precision of an apparatus is important (not important) because...

**UE Adapting 1 Q2 - Apr 19, 2018**

Knowing that the equipment may have multiple uses is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, knowing that the equipment may have multiple uses is important (not important) because...

For an EXPERIMENTAL PHYSICIST, knowing that the equipment may have multiple uses is important (not important) because...

### UE Adapting 2 Q2 - Apr 19, 2018

Knowing how to adapt equipment to new situations is useful

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, knowing how to adapt equipment to new situations is useful (not useful) because...

For an EXPERIMENTAL PHYSICIST, knowing how to adapt equipment to new situations is useful (not useful) because...

**UE Troubleshooting 1 Q2 - Apr 19, 2018**

Knowing how to fix the equipment when it is broken is useful

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | ○ | ○ | ○ | ○ | ○ |
| What would an EXPERIMENTAL PHYSICIST say about their research | ○ | ○ | ○ | ○ | ○ |

For ME, knowing how to fix the equipment when it is broken is useful (not useful) because...

For an EXPERIMENTAL PHYSICIST, knowing how to fix the equipment when it is broken is useful (not useful) because...

**C Presenting 6 Q1 - Apr 19, 2018**

Explaining what I did is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, explaining what I did is important (not important) because...

For an EXPERIMENTAL PHYSICIST, explaining what I did is important (not important) because...

**C Presenting 7 Q1 - Apr 19, 2018**

Explaining why I did what I did is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, explaining why I did what I did is important (not important) because...

For an EXPERIMENTAL PHYSICIST, explaining why I did what I did is important (not important) because...

**C Presenting 8 Q1 - Apr 19, 2018**

Explaining how I did what I did is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, explaining how I did what I did is important (not important) because...

For an EXPERIMENTAL PHYSICIST, explaining how I did what I did is important (not important) because...

**C Presenting 9 Q1 - Apr 19, 2018**

Explaining what my results mean is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | ○ | ○ | ○ | ○ | ○ |
| What would an EXPERIMENTAL PHYSICIST say about their research | ○ | ○ | ○ | ○ | ○ |

For ME, explaining what my results mean is important (not important) because...

For an EXPERIMENTAL PHYSICIST, explaining what my results mean is important (not important) because...

**C Presenting 10 Q1 - Apr 19, 2018**

Presenting what my results mean is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, presenting what my results mean is important (not important) because...

For an EXPERIMENTAL PHYSICIST, presenting what my results mean is important (not important) because...

### C Presenting 11 Q1 - Apr 19, 2018

Presenting what I did is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, presenting what I did is important (not important) because...

For an EXPERIMENTAL PHYSICIST, presenting what I did is important (not important) because...

### C Explaining 1 Q1 - Apr 19, 2018

Explaining what I found is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, explaining what I found is important (not important) because...

For an EXPERIMENTAL PHYSICIST, explaining what I found is important (not important) because...

**C Explaining 2 Q1 - Apr 19, 2018**

Explaining what I was trying to do is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, explaining what I was trying to do is important (not important) because...

For an EXPERIMENTAL PHYSICIST, explaining what I was trying to do is important (not important) because...

**C Explaining 3 Q1 - Apr 19, 2018**

Explaining what it means is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, explaining what it means is important (not important) because...

For an EXPERIMENTAL PHYSICIST, explaining what it means is important (not important) because...

**C Explaining 4 Q1 - Apr 19, 2018**

Explaining my results is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, explaining my results is important (not important) because...

For an EXPERIMENTAL PHYSICIST, explaining my results is important (not important) because...

**C Explaining 5 Q1 - Apr 19, 2018**

Explaining my interpretation of the results is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, explaining my interpretation of the results is important (not important) because...

For an EXPERIMENTAL PHYSICIST, explaining my interpretation of the results is important (not important) because...

**C Presenting 1 Q2 - Apr 19, 2018**

Communicating my results by answering specific questions is helpful

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, communicating my results by answering specific questions is helpful (not helpful) because...

For an EXPERIMENTAL PHYSICIST, communicating my results by answering specific questions is helpful (not helpful) because...

**C Presenting 2 Q2 - Apr 19, 2018**

Communicating my results by writing in my lab notebook is helpful

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, communicating my results by writing in my lab notebook is helpful (not helpful) because...

For an EXPERIMENTAL PHYSICIST, communicating my results by writing in my lab notebook is helpful (not helpful) because...

**C Presenting 3 Q2 - Apr 19, 2018**

Communicating my results by writing up a conclusion is helpful

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | ○ | ○ | ○ | ○ | ○ |
| What would an EXPERIMENTAL PHYSICIST say about their research | ○ | ○ | ○ | ○ | ○ |

For ME, communicating my results by writing up a conclusion is helpful (not helpful) because...

For an EXPERIMENTAL PHYSICIST, communicating my results by writing up a conclusion is helpful (not helpful) because...

**C Presenting 4 Q2 - Apr 19, 2018**

Communicating my results with data tables, graphs, and pictures is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | ○ | ○ | ○ | ○ | ○ |

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What would an EXPERIMENTAL PHYSICIST say about their research | ○ | ○ | ○ | ○ | ○ |

For ME, communicating my results with data tables, graphs, and pictures is important (not important) because...

For an EXPERIMENTAL PHYSICIST, communicating my results with data tables, graphs, and pictures is important (not important) because...

**C Presenting 5 Q2 - Apr 19, 2018**

Being able to communicate my understanding is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | ○ | ○ | ○ | ○ | ○ |
| What would an EXPERIMENTAL PHYSICIST say about their research | ○ | ○ | ○ | ○ | ○ |

For ME, being able to communicate my understanding is important (not important) because...

For an EXPERIMENTAL PHYSICIST, being able to communicate my understanding is important (not important) because...

**C Uncertainty 1 Q2 - Apr 19, 2018**

Communicating my results with confidence is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, communicating my results with confidence is important (not important) because...

For an EXPERIMENTAL PHYSICIST, communicating my results with confidence is important (not important) because...

**C Uncertainty 2 Q2 - Apr 19, 2018**

Using uncertainty to express the confidence in my results is helpful

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, using uncertainty to express the confidence in my results is helpful (not helpful) because...

For an EXPERIMENTAL PHYSICIST, using uncertainty to express the confidence in my results is helpful (not helpful) because...

**PE What 1 Q1 - Apr 19, 2018**

Having an hypothesis when planning an experiment is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, having an hypothesis when planning an experiment is important (not important) because...

For an EXPERIMENTAL PHYSICIST, having an hypothesis when planning an experiment is important (not important) because...

**PE What 2 Q1 - Apr 19, 2018**

Knowing what my goal is when planning an experiment is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, knowing what my goal is when planning an experiment is important (not important) because...

For an EXPERIMENTAL PHYSICIST, knowing what my goal is when planning an experiment is important (not important) because...

**PE What 3 Q1 - Apr 19, 2018**

Knowing what I am trying to find out is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, knowing what I am trying to find out is important (not important) because...

For an EXPERIMENTAL PHYSICIST, knowing what I am trying to find out is important (not important) because...

**PE What 4 Q1 - Apr 19, 2018**

Knowing how to get to my goal when planning an experiment is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, knowing how to get to my goal when planning an experiment is important (not important) because...

For an EXPERIMENTAL PHYSICIST, knowing how to get to my goal when planning an experiment is important (not important) because...

**PE How 1 Q1 - Apr 19, 2018**

Having a plan to answer my questions is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, having a plan to answer my questions is important (not important) because...

For an EXPERIMENTAL PHYSICIST, having a plan to answer my questions is important (not important) because...

**PE How 2 Q1 - Apr 19, 2018**

Having a plan to get to my goal is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, having a plan to get to my goal is important (not important) because...

For an EXPERIMENTAL PHYSICIST, having a plan to get to my goal is important (not important) because...

**PE How 3 Q1 - Apr 19, 2018**

Knowing what equipment I need for the experiment I am planning is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | ○ | ○ | ○ | ○ | ○ |
| What would an EXPERIMENTAL PHYSICIST say about their research | ○ | ○ | ○ | ○ | ○ |

For ME, knowing what equipment I need for the experiment I am planning is important (not important) because...

For an EXPERIMENTAL PHYSICIST, knowing what equipment I need for the experiment I am planning is important (not important) because...

**PE How 4 Q1 - Apr 19, 2018**

Knowing what design works best for the experiment I am planning is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, knowing what design works best for the experiment I am planning is important (not important) because...

For an EXPERIMENTAL PHYSICIST, knowing what design works best for the experiment I am planning is important (not important) because...

**PE Procedure 1 Q1 - Apr 19, 2018**

Having a procedure when designing an experiment is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | ○ | ○ | ○ | ○ | ○ |
| What would an EXPERIMENTAL PHYSICIST say about their research | ○ | ○ | ○ | ○ | ○ |

For ME, having a procedure when designing an experiment is important (not important) because...

For an EXPERIMENTAL PHYSICIST, having a procedure when designing an experiment is important (not important) because...

**PE Procedure 2 Q1 - Apr 19, 2018**

Creating a procedure when designing an experiment is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, creating a procedure when designing an experiment is important (not important) because...

For an EXPERIMENTAL PHYSICIST, creating a procedure when designing an experiment is important (not important) because...

**PE Procedure 3 Q1 - Apr 19, 2018**

Planning out the steps when designing an experiment is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, planning out the steps when designing an experiment is important (not important) because...

For an EXPERIMENTAL PHYSICIST, planning out the steps when designing an experiment is important (not important) because...

**PE Procedure 4 Q1 - Apr 19, 2018**

Figuring out how to get the information I need when desiging an experiment is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, figuring out how to get the information I need when desiging an experiment is important (not important) because...

For an EXPERIMENTAL PHYSICIST, figuring out how to get the information I need when desiging an experiment is important (not important) because...

**PE Procedure 5 Q1 - Apr 19, 2018**

Figuring out how to set up the equipment when planning an experiment is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, figuring out how to set up the equipment when planning an experiment is important (not important) because...

For an EXPERIMENTAL PHYSICIST, figuring out how to set up the equipment when planning an experiment is important (not important) because...

**PE Procedure 6 Q1 - Apr 19, 2018**

Figuring out how to get the equipment and measurement devices into the system when designing an experiment is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, figuring out how to get the equipment and measurement devices into the system when designing an experiment is important (not important) because...

For an EXPERIMENTAL PHYSICIST, figuring out how to get the equipment and measurement devices into the system when designing an experiment is important (not important) because...

**EE Data 1 Q1 - Apr 19, 2018**

Doing calculations is helpful

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, doing calculations is helpful (not helpful) because...

For an EXPERIMENTAL PHYSICIST, doing calculations is helpful (not helpful) because...

**EE Data 2 Q1 - Apr 19, 2018**

Working with the equipment is valuable

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, working with the equipment is valuable (not valuable) because...

For an EXPERIMENTAL PHYSICIST, working with the equipment is valuable (not valuable) because...

**EE Data 3 Q1 - Apr 19, 2018**

Collecting data and taking measurements is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, collecting data and taking measurements is important (not important) because...

For an EXPERIMENTAL PHYSICIST, collecting data and taking measurements is important (not important) because...

**EE Uncertainty 1 Q1 - Apr 19, 2018**

The fact that uncertainty means measurements may be off, inaccurate, or wrong is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, the fact that uncertainty means measurements may be off, inaccurate, or wrong is important (not important) because...

For an EXPERIMENTAL PHYSICIST, the fact that uncertainty means measurements may be off, inaccurate, or wrong is important (not important) because...

**EE Uncertainty 2 Q1 - Apr 19, 2018**

Knowing that the uncertainty my have an impact on the experiment is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, knowing that the uncertainty my have an impact on the experiment is important (not important) because...

For an EXPERIMENTAL PHYSICIST, knowing that the uncertainty my have an impact on the experiment is important (not important) because...

**EE Uncertainty 3 Q1 - Apr 19, 2018**

Knowing that there is uncertainty associated with our measurements is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, knowing that there is uncertainty associated with our measurements is important (not important) because...

For an EXPERIMENTAL PHYSICIST, knowing that there is uncertainty associated with our measurements is important (not important) because...

**EE Uncertainty 4 Q1 - Apr 19, 2018**

Working to minimize the uncertainty in my experiment is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, working to minimize the uncertainty in my experiment is important (not important) because...

For an EXPERIMENTAL PHYSICIST, working to minimize the uncertainty in my experiment is important (not important) because...

**DA Math 1 Q1 - Apr 19, 2018**

Doing calculations with data is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, doing calculations with data is important (not important) because...

For an EXPERIMENTAL PHYSICIST, doing calculations with data is important (not important) because...

**DA Math 2 Q1 - Apr 19, 2018**

Doing math with my data in order to get my results is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | ○ | ○ | ○ | ○ | ○ |
| What would an EXPERIMENTAL PHYSICIST say about their research | ○ | ○ | ○ | ○ | ○ |

For ME, doing math with my data in order to get my results is important (not important) because...

For an EXPERIMENTAL PHYSICIST, doing math with my data in order to get my results is important (not important) because...

**DA Math 3 Q1 - Apr 19, 2018**

Using math as a tool to explain and predict is helpful

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, using math as a tool to explain and predict is helpful (not helpful) because...

For an EXPERIMENTAL PHYSICIST, using math as a tool to explain and predict is helpful (not helpful) because...

**DA Math 5 Q1 - Apr 19, 2018**

Using math to apply a pattern to what I saw is valuable

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, using math to apply a pattern to what I saw is valuable (not valuable) because...

For an EXPERIMENTAL PHYSICIST, using math to apply a pattern to what I saw is valuable (not valuable) because...

**DA Math 6 Q1 - Apr 19, 2018**

Calculating the average value for each variable tested/measured is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, calculating the average value for each variable tested/measured is important (not important) because...

For an EXPERIMENTAL PHYSICIST, calculating the average value for each variable tested/measured is important (not important) because...

**DA Connections 1 Q1 - Apr 19, 2018**

Making connections to the bigger concepts is valuable

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, making connections to the bigger concepts is valuable (not valuable) because...

For an EXPERIMENTAL PHYSICIST, making connections to the bigger concepts is valuable (not valuable) because...

**DA Connections 2 Q1 - Apr 19, 2018**

Using the concepts to make my data into something I can interpret is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, using the concepts to make my data into something I can interpret is important (not important) because...

For an EXPERIMENTAL PHYSICIST, using the concepts to make my data into something I can interpret is important (not important) because...

**DA Trends/Patterns 1 Q1 - Apr 19, 2018**

Observing trends and patterns in the experiment and applying equations to that is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, observing trends and patterns in the experiment and applying equations to that is important (not important) because...

For an EXPERIMENTAL PHYSICIST, observing trends and patterns in the experiment and applying equations to that is important (not important) because...

**DA Trends/Patterns 2 Q1 - Apr 19, 2018**

Determining patterns from my data is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, determining patterns from my data is important (not important) because...

For an EXPERIMENTAL PHYSICIST, determining patterns from my data is important (not important) because...

**DA Trends/Patterns 3 Q1 - Apr 19, 2018**

Looking for trends or asking why something happened mathematically is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, looking for trends or asking why something happened mathematically is important (not important) because...

For an EXPERIMENTAL PHYSICIST, looking for trends or asking why something happened mathematically is important (not important) because...

**DA Graphing 1 Q2 - Apr 19, 2018**

Using graphs to interpret results is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, using graphs to interpret results is important (not important) because...

For an EXPERIMENTAL PHYSICIST, using graphs to interpret results is important (not important) because...

**DA Graphing 2 Q2 - Apr 19, 2018**

Making graphs from collected data is helpful

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, making graphs from collected data is helpful (not helpful) because...

For an EXPERIMENTAL PHYSICIST, making graphs from collected data is helpful (not helpful) because...

**DA Graphing 3 Q2 - Apr 19, 2018**

Interpreting graphs to understand relationships between parameters is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, interpreting graphs to understand relationships between parameters is important (not important) because...

For an EXPERIMENTAL PHYSICIST, interpreting graphs to understand relationships between parameters is important (not important) because...

**DA Comparing 1 Q2 - Apr 19, 2018**

Comparing my results to the expected is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, comparing my results to the expected is important (not important) because...

For an EXPERIMENTAL PHYSICIST, comparing my results to the expected is important (not important) because...

**DA Comparing 2 Q2 - Apr 19, 2018**

Determining if my data matches what I expected is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, determining if my data matches what I expected is important (not important) because...

For an EXPERIMENTAL PHYSICIST, determining if my data matches what I expected is important (not important) because...

**DA Significance 3 Q2 - Apr 19, 2018**

Using data to determine the significance of my results is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | ○ | ○ | ○ | ○ | ○ |
| What would an EXPERIMENTAL PHYSICIST say about their research | ○ | ○ | ○ | ○ | ○ |

For ME, using data to determine the significance of my results is important (not important) because...

For an EXPERIMENTAL PHYSICIST, using data to determine the significance of my results is important (not important) because...

**DA Uncertainty 1 Q2 - Apr 19, 2018**

Testing the validity of my results with uncertainty is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | ○ | ○ | ○ | ○ | ○ |
| What would an EXPERIMENTAL PHYSICIST say about their research | ○ | ○ | ○ | ○ | ○ |

For ME, testing the validity of my results with uncertainty is important (not important) because...

For an EXPERIMENTAL PHYSICIST, testing the validity of my results with uncertainty is important (not important) because...

**DA Uncertainty 2 Q2 - Apr 19, 2018**

Expressing confidence in my results with uncertainty is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | ○ | ○ | ○ | ○ | ○ |
| What would an EXPERIMENTAL PHYSICIST say about their research | ○ | ○ | ○ | ○ | ○ |

For ME, expressing confidence in my results with uncertainty is important (not important) because...

For an EXPERIMENTAL PHYSICIST, expressing confidence in my results with uncertainty is important (not important) because...

**DA Math 4 Q2 - Apr 19, 2018**

Looking for trends in my data is important

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | ○ | ○ | ○ | ○ | ○ |

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, looking for trends in my data is important (not important) because...

For an EXPERIMENTAL PHYSICIST, looking for trends in my data is important (not important) because...

**End Community Block**

While taking this survey I was most frequently thinking of myself as a member of this community (select all that apply)

Science student

Person in my major

A person with a future in ${q://QID4/ChoiceGroup/SelectedChoices}

An aware citizen

Curious person

${q://QID28/ChoiceTextEntryValue/4}

Is there anything you would like to tell us about the experience of taking this survey

**Example Block**

Doing calculations is helpful

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| What do YOU think | O | O | O | O | O |
| What would an EXPERIMENTAL PHYSICIST say about their research | O | O | O | O | O |

For ME, doing calculations is helpful (not helpful) because...

For an EXPERIMENTAL PHYSICIST, doing calculations is helpful (not helpful) because...

# APPENDIX I

## SURVEY VERSION 2

This appendix has the entire survey from Version 2 (Sec. 6.4). This is how it would have been viewed by each student on Qualtrics[1]. The students saw a random practice question and four of the ten reasoning questions. The practice questions are not individually labeled in this appendix, the main purpose of this is to provide a visual of what the students saw when taking the survey.

[1]Qualtrics, 2019, Qualtrics Labs, Inc. Provo, UT, USA

about your role and rights as a research participant, would like to obtain information or offer input, or would like to register a complaint about this study, you may contact, anonymously if you wish, the Michigan State University's Human Research Protection Program at 517-355-2180, Fax 517-432-4503, or e-mail irb@msu.edu or regular mail at Olds Hall, 408 West Circle Drive #207, MSU, East Lansing, MI 48824.

9. DOCUMENTATION OF INFORMED CONSENT.

Your affirmations below means that you voluntarily agree to participate in this research study.

Do you agree to participate in the study?
An answer is required.

Yes
No

What physics class(es) are you in currently?

What is your current major?

Why did you choose to major in science?

What is your interest in physics?

Very low
Low
Moderate
High
Very high

What are your future plans?

If you selected OTHER please briefly describe your future plans

As an undergraduate student taking science classes you are part of many different communities. These communities may influence your perspective as you go through your undergraduate career. Below we have some examples of communities that may be relevant to you, please choose all that apply and add on if we are missing something.

I think of myself as a ...
(Choose all that apply)

Science student
Person in my major
A person with a future in ${q://QID172/ChoiceGroup/SelectedChoices}
An aware citizen
Curious person
Other:

When you think of your future career who do you imagine working with? (For example: Teacher work with students, doctors work with patients)
(choose the one that best fits)

Students
Patients
Clients
Other

PLEASE READ BEFORE PROCEEDING

The rest of the questions are focused on your experience in physics labs. A set of two questions will be addressing the same idea. **There are no wrong answers**, we are just looking for your opinion on these things.

This will look like:
Do YOU agree/disagree with this statement?

Did these reasons contribute to your answer to the previous question?
REASON 1
REASON 2
REASON 3
REASON 4

------

The majority of this survey is multiple choice. There is space at the end for you to make additional comments.

If you find that the reasons provided do not sufficiently cover your own reasoning there will be space at the end for you to add other reasons.

**C1**

Explaining what I found is important

| Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
| --- | --- | --- | --- | --- |

Explaining what I was trying to do is important

| Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
| --- | --- | --- | --- | --- |

Explaining what I did is important

| Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
| --- | --- | --- | --- | --- |

Explaining why I did what I did is important

Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree

Explaining how I did what I did is important

Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree

Explaining my interpretation of the results is important

Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree

Explaining my results is important

Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree

I answered the previous question the way I did because

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|---|
| It might be helpful but I felt obligated to do it in the class | ○ | ○ | ○ | ○ | ○ |
| This will help me in the future | ○ | ○ | ○ | ○ | ○ |
| It is important at times but it does not apply to me | ○ | ○ | ○ | ○ | ○ |
| I do not care about this but I felt like I had to do it for the class | ○ | ○ | ○ | ○ | ○ |

**C2**

Explaining what my results mean is important

Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree

Presenting what my results mean is important

Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree

Presenting what I did is important

Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree

Communicating my results by answering specific questions is helpful

Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree

Communicating my results by writing in my lab notebook is helpful

Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree

Communicating my results by writing up a conclusion is helpful

Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree

Being able to communicate my understanding is important

Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree

Using uncertainty to express the confidence in my results is helpful

Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree

I answered the previous question the way I did because

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree |
|---|---|---|---|---|

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree |
|---|---|---|---|---|
| » This is not something I need to know for my career | ○ | ○ | ○ | ○ |
| » This will help me in the future | ○ | ○ | ○ | ○ |
| » I will not use this again after this class | ○ | ○ | ○ | ○ |
| » It is not the most important thing to me | ○ | ○ | ○ | ○ |
| » It is important at times but it does not apply to me | ○ | ○ | ○ | ○ |
| » It is important to think about but not always necessary | ○ | ○ | ○ | ○ |
| » I do not care about this but I felt like I had to do it for the class | ○ | ○ | ○ | ○ |
| » It might be helpful but I felt obligated to do it in the class | ○ | ○ | ○ | ○ |
| » This is important but I did it because I was expected to | ○ | ○ | ○ | ○ |
| » This will be important when working with ${q://QID99/ChoiceGroup/SelectedChoicesTextEntry} | ○ | ○ | ○ | ○ |

**DA1**

Using math as a tool to explain and predict is helpful

| Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|

Using math to apply a pattern to what I saw is valuable

| Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|

Calculating the average value for each variable tested/measured is important

| Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|

Observing trends and patterns in the experiment and applying equations to that is important

| Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|

Determining patterns from my data is important

Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree

Looking for trends or asking why something happened mathematically is important

Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree

Doing math with my data in order to get my results is important

Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree

I answered the previous question the way I did because

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree |
|---|---|---|---|---|
| » This is not something I need to know for my career | ○ | ○ | ○ | ○ |
| » This will help me in the future | ○ | ○ | ○ | ○ |
| » I will not use this again after this class | ○ | ○ | ○ | ○ |
| » It is not the most important thing to me | ○ | ○ | ○ | ○ |
| » It is important at times but it does not apply to me | ○ | ○ | ○ | ○ |
| » It is important to think about but not always necessary | ○ | ○ | ○ | ○ |
| » I do not care about this but I felt like I had to do it for the class | ○ | ○ | ○ | ○ |
| » It might be helpful but I felt obligated to do it in the class | ○ | ○ | ○ | ○ |
| » This is important but I did it because I was expected to | ○ | ○ | ○ | ○ |
| » This will be important when working with ${q://QID99/ChoiceGroup/SelectedChoicesTextEntry} | ○ | ○ | ○ | ○ |

**DA2**

Making connections to the bigger concepts is valuable

| Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|

Using the concepts to make my data into something I can interpret is important

| Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|

Comparing my results to the expected is important

| Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|

Using graphs to interpret results is important

| Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|

Making graphs from collected data is helpful

| Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|

Interpreting graphs to understand relationships between parameters is important

| Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|

Using data to determine the significance of my results is important

| Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|

Testing the validity of my results with uncertainty is important

| Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|

Expressing confidence in my results with uncertainty is important

| Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|

I answered the previous question the way I did because

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree |
|---|---|---|---|---|
| » This is not something I need to know for my career | ○ | ○ | ○ | ○ |
| » This will help me in the future | ○ | ○ | ○ | ○ |
| » I will not use this again after this class | ○ | ○ | ○ | ○ |
| » It is not the most important thing to me | ○ | ○ | ○ | ○ |
| » It is important at times but it does not apply to me | ○ | ○ | ○ | ○ |
| » It is important to think about but not always necessary | ○ | ○ | ○ | ○ |
| » I do not care about this but I felt like I had to do it for the class | ○ | ○ | ○ | ○ |
| » It might be helpful but I felt obligated to do it in the class | ○ | ○ | ○ | ○ |
| » This is important but I did it because I was expected to | ○ | ○ | ○ | ○ |
| » This will be important when working with ${q://QID99/ChoiceGroup/SelectedChoicesTextEntry} | ○ | ○ | ○ | ○ |

**EE1**

Working with the equipment is valuable

Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree

Collecting data and taking measurements is important

Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree

Knowing that there is uncertainty associated with our measurements is important

Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree

Working to minimize the uncertainty in my experiment is important

Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree

The fact that uncertainty means measurements may be off, inaccurate, or wrong is important

Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree

Knowing that the uncertainty my have an impact on the experiment is important

Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree

I answered the previous question the way I did because

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree |
|---|---|---|---|---|
| » This is not something I need to know for my career | ○ | ○ | ○ | ○ |
| » This will help me in the future | ○ | ○ | ○ | ○ |
| » I will not use this again after this class | ○ | ○ | ○ | ○ |
| » It is not the most important thing to me | ○ | ○ | ○ | ○ |
| » It is important at times but it does not apply to me | ○ | ○ | ○ | ○ |
| » It is important to think about but not always necessary | ○ | ○ | ○ | ○ |
| » I do not care about this but I felt like I had to do it for the class | ○ | ○ | ○ | ○ |
| » It might be helpful but I felt obligated to do it in the class | ○ | ○ | ○ | ○ |
| » This is important but I did it because I was expected to | ○ | ○ | ○ | ○ |
| » This will be important when working with ${q://QID99/ChoiceGroup/SelectedChoicesTextEntry} | ○ | ○ | ○ | ○ |

**GW1**

Bringing many ideas together in a group is important

Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree

Bouncing ideas off of my group members is important

| Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|

Communicating with my group about how things work is important

| Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|

Everyone feeling comfortable sharing their ideas in their group is important

| Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|

Letting each group member have hands-on time with the equipment is important

| Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|

Agreeing as a group on how to complete a task before moving forward is important

| Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|

Valuing every group member's ideas is important

| Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|

Communicating with my group about how to do things is important

| Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|

Communicating with my group about the results is important

| Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|

I answered the previous question the way I did because

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree |
|---|---|---|---|---|
| » This is not something I need to know for my career | ○ | ○ | ○ | ○ |
| » This will help me in the future | ○ | ○ | ○ | ○ |
| » I will not use this again after this class | ○ | ○ | ○ | ○ |
| » It is not the most important thing to me | ○ | ○ | ○ | ○ |
| » It is important at times but it does not apply to me | ○ | ○ | ○ | ○ |
| » It is important to think about but not always necessary | ○ | ○ | ○ | ○ |
| » I do not care about this but I felt like I had to do it for the class | ○ | ○ | ○ | ○ |
| » It might be helpful but I felt obligated to do it in the class | ○ | ○ | ○ | ○ |
| » This is important but I did it because I was expected to | ○ | ○ | ○ | ○ |
| » This will be important when working with ${q://QID99/ChoiceGroup/SelectedChoicesTextEntry} | ○ | ○ | ○ | ○ |

**GW2**

Everyone in the group contributing an equal amount is important

Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree

Giving everyone in the group a chance to contribute is important

Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree

Figuring out how to communicate with my group is important

Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree

Caring about how each member of my group sees my work/effort is important

Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree

Having help from my group to check my work is important

Strongly agree Somewhat agree Neither agree nor disagree Somewhat disagree Strongly disagree

Having help from my group if I have questions is important

Strongly agree Somewhat agree Neither agree nor disagree Somewhat disagree Strongly disagree

Working together as a group is important

Strongly agree Somewhat agree Neither agree nor disagree Somewhat disagree Strongly disagree

Making decisions together as a group is important

Strongly agree Somewhat agree Neither agree nor disagree Somewhat disagree Strongly disagree

I answered the previous question the way I did because

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree |
|---|---|---|---|---|
| » This is not something I need to know for my career | ○ | ○ | ○ | ○ |
| » This will help me in the future | ○ | ○ | ○ | ○ |
| » I will not use this again after this class | ○ | ○ | ○ | ○ |
| » It is not the most important thing to me | ○ | ○ | ○ | ○ |
| » It is important at times but it does not apply to me | ○ | ○ | ○ | ○ |
| » It is important to think about but not always necessary | ○ | ○ | ○ | ○ |
| » I do not care about this but I felt like I had to do it for the class | ○ | ○ | ○ | ○ |
| » It might be helpful but I felt obligated to do it in the class | ○ | ○ | ○ | ○ |
| » This is important but I did it because I was expected to | ○ | ○ | ○ | ○ |
| » This will be important when working with ${q://QID99/ChoiceGroup/SelectedChoicesTextEntry} | ○ | ○ | ○ | ○ |

**PE1**

Having an hypothesis when planning an experiment is important

| Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|

Having a plan to answer my questions is important

| Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|

Knowing what my goal is when planning an experiment is important

| Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|

Having a plan to get to my goal is important

| Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|

Knowing what equipment I need for the experiment I am planning is important

| Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|

Knowing what design works best for the experiment I am planning is important

| Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|

Having a procedure when designing an experiment is important

| Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|

Figuring out how to get the information I need when desiging an experiment is important

| Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|

Figuring out how to set up the equipment when planning an experiment is important

Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree

Knowing how to get to my goal when planning an experiment is important

Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree

I answered the previous question the way I did because

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree |
|---|---|---|---|---|
| » This is not something I need to know for my career | ○ | ○ | ○ | ○ |
| » This will help me in the future | ○ | ○ | ○ | ○ |
| » I will not use this again after this class | ○ | ○ | ○ | ○ |
| » It is not the most important thing to me | ○ | ○ | ○ | ○ |
| » It is important at times but it does not apply to me | ○ | ○ | ○ | ○ |
| » It is important to think about but not always necessary | ○ | ○ | ○ | ○ |
| » I do not care about this but I felt like I had to do it for the class | ○ | ○ | ○ | ○ |
| » It might be helpful but I felt obligated to do it in the class | ○ | ○ | ○ | ○ |
| » This is important but I did it because I was expected to | ○ | ○ | ○ | ○ |
| » This will be important when working with ${q://QID99/ChoiceGroup/SelectedChoicesTextEntry} | ○ | ○ | ○ | ○ |

**UE1**

Trying out the equipment and seeing what it does is valuable

Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree

Tinkering with the equipment is useful

Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree

Knowing what the equipment is designed to measure is valuable

Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree

Knowing how the parts of the equipment work is valuable

Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree

Knowing how to get what I need from the equipment is important

Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree

Knowing how the equipment works is important

Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree

Seeing how changing one component of the equipment affects something else is important

Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree

I answered the previous question the way I did because

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree |
|---|---|---|---|---|
| » This is not something I need to know for my career | ○ | ○ | ○ | ○ |
| » This will help me in the future | ○ | ○ | ○ | ○ |
| » I will not use this again after this class | ○ | ○ | ○ | ○ |
| » It is not the most important thing to me | ○ | ○ | ○ | ○ |
| » It is important at times but it does not apply to me | ○ | ○ | ○ | ○ |
| » It is important to think about but not always necessary | ○ | ○ | ○ | ○ |
| » I do not care about this but I felt like I had to do it for the class | ○ | ○ | ○ | ○ |

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree |
|---|---|---|---|---|
| » It might be helpful but I felt obligated to do it in the class | ○ | ○ | ○ | ○ |
| » This is important but I did it because I was expected to | ○ | ○ | ○ | ○ |
| » This will be important when working with ${q://QID99/ChoiceGroup/SelectedChoicesTextEntry} | ○ | ○ | ○ | ○ |

**UE2**

Knowing that the equipment may have multiple uses is important

Strongly agree Somewhat agree Neither agree nor disagree Somewhat disagree Strongly disagree

Knowing how to adapt equipment to new situations is useful

Strongly agree Somewhat agree Neither agree nor disagree Somewhat disagree Strongly disagree

Identifying the extreme settings of the equipment is important

Strongly agree Somewhat agree Neither agree nor disagree Somewhat disagree Strongly disagree

Making the equipment measure something it was not originally intended for is important

Strongly agree Somewhat agree Neither agree nor disagree Somewhat disagree Strongly disagree

Knowing what not to do with the equipment is useful

Strongly agree Somewhat agree Neither agree nor disagree Somewhat disagree Strongly disagree

Knowing the limits/capabilities of the equipment is useful

Strongly agree Somewhat agree Neither agree nor disagree Somewhat disagree Strongly disagree

Knowing how to fix the equipment when it is broken is useful

| Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|

I answered the previous question the way I did because

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree |
|---|---|---|---|---|
| » This is not something I need to know for my career | ○ | ○ | ○ | ○ |
| » This will help me in the future | ○ | ○ | ○ | ○ |
| » I will not use this again after this class | ○ | ○ | ○ | ○ |
| » It is not the most important thing to me | ○ | ○ | ○ | ○ |
| » It is important at times but it does not apply to me | ○ | ○ | ○ | ○ |
| » It is important to think about but not always necessary | ○ | ○ | ○ | ○ |
| » I do not care about this but I felt like I had to do it for the class | ○ | ○ | ○ | ○ |
| » It might be helpful but I felt obligated to do it in the class | ○ | ○ | ○ | ○ |
| » This is important but I did it because I was expected to | ○ | ○ | ○ | ○ |
| » This will be important when working with ${q://QID99/ChoiceGroup/SelectedChoicesTextEntry} | ○ | ○ | ○ | ○ |

**End Block**

Do you see yourself as a physics person?

| No, not at all 1 | 2 | 3 | 4 | 5 | Yes, very much 6 |
|---|---|---|---|---|---|

While taking this survey I was most frequently thinking of myself as a member of this community (select all that apply)

Science student
Person in my major
A person with a future in
An aware citizen
Curious person
${q://QID226/ChoiceTextEntryValue/4}

${q://QID223/ChoiceGroup/SelectedChoices}

While taking the survey did you find the options provided under 'I answered the previous question the way I did because' sufficiently covered your own reasoning?

Yes

Sometimes

No

If you believe some options were missing please include them below

Is there anything you would like to tell us about the experience of taking this survey?

# APPENDIX J

## SURVEY VERSION 3

This appendix has the entire survey from Version 3 (Sec. 6.5). This is how it would have been viewed by each student on Qualtrics[1]. The students saw a random practice question and all six reasoning questions. The practice questions are not individually labeled in this appendix, the main purpose of this is to provide a visual of what the students saw when taking the survey. Note: the identity reasoning questions have a choicce that is partially cutoff on the right side. The cutoff option is 'Strongly disagree.'

[1]Qualtrics, 2019, Qualtrics Labs, Inc. Provo, UT, USA

about your role and rights as a research participant, would like to obtain information or offer input, or would like to register a complaint about this study, you may contact, anonymously if you wish, the Michigan State University's Human Research Protection Program at 517-355-2180, Fax 517-432-4503, or e-mail irb@msu.edu or regular mail at Olds Hall, 408 West Circle Drive #207, MSU, East Lansing, MI 48824.

9. DOCUMENTATION OF INFORMED CONSENT.

Your affirmations below means that you voluntarily agree to participate in this research study.

Do you agree to participate in the study?
An answer is required.

Yes

No

What physics class(es) are you in currently?

What is your current major?

Why did you choose to major in science?

What is your interest in physics?

Very low

Low

Moderate

High

Very high

What are your future plans?

If you selected OTHER please briefly describe your future plans

As an undergraduate student taking science classes you are part of many different communities. These communities may influence your perspective as you go through your undergraduate career. Below we have some examples of communities that may be relevant to you, please choose all that apply and add on if we are missing something.

I think of myself as a ...
(Choose all that apply)

Science student
Person in my major
A person with a future in ${q://QID172/ChoiceGroup/SelectedChoices}
An aware citizen
Curious person
Other:

When you think of your future career who do you imagine working with? (For example: Teacher work with students, doctors work with patients)
(choose the one that best fits)

Students
Patients
Clients
Peers/Colleagues
Other

PLEASE READ BEFORE PROCEEDING

The rest of the questions are focused on your experience in physics labs. A set of two questions will be addressing the same idea. **There are no wrong answers**, we are just looking for your opinion on these things.

This will look like:
Do YOU agree/disagree with this statement?

Did these reasons contribute to your answer to the previous question?
REASON 1
REASON 2
REASON 3
REASON 4
REASON 5
REASON 6

------

The majority of this survey is multiple choice. There is space at the end for you to make additional comments.

If you find that the reasons provided do not sufficiently cover your own reasoning there will be space at the end for you to add other reasons.

**C1**

Explaining what I was trying to do is important

| Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|

Explaining what I did is important

| Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|

Presenting what I did is important

| Strongly agree | Somewhat agree | Neither agree nor | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|

disagree

I answered the previous question the way I did because ...
(Consider the entire statement when choosing your response)

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Stro disa |
|---|---|---|---|---|---|
| I will not use this again after this class | ○ | ○ | ○ | ○ | ○ |
| It is important to think about but not always necessary | ○ | ○ | ○ | ○ | ○ |
| This will help me in the future | ○ | ○ | ○ | ○ | ○ |
| This will be important when working with ${q://QID55/ChoiceGroup/SelectedChoicesTextEntry} | ○ | ○ | ○ | ○ | ○ |
| This is important but I did it because I had to | ○ | ○ | ○ | ○ | ○ |
| It is not the most important thing to me | ○ | ○ | ○ | ○ | ○ |

**C2**

Explaining what my results mean is important

| Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|

Communicating my results by writing in my lab notebook is helpful

| Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|

Communicating my results by writing up a conclusion is helpful

| Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|

I answered the previous question the way I did because ...
(Consider the entire statement when choosing your response)

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Stro disa |
|---|---|---|---|---|---|
| » This will be important when working with ${q://QID55/ChoiceGroup/SelectedChoicesTextEntry} | ○ | ○ | ○ | ○ | ○ |
| » I will not use this again after this class | ○ | ○ | ○ | ○ | ○ |
| » This will help me in the future | ○ | ○ | ○ | ○ | ○ |
| » It is not the most important thing to me | ○ | ○ | ○ | ○ | ○ |
| » This is important but I did it because I had to | ○ | ○ | ○ | ○ | ○ |
| » It is important to think about but not always necessary | ○ | ○ | ○ | ○ | ○ |

**C3**

Being able to communicate my understanding is important

| Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|

Explaining what I found is important

| Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|

I answered the previous question the way I did because ...
(Consider the entire statement when choosing your response)

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Stro disa |
|---|---|---|---|---|---|
| » This will be important when working with ${q://QID55/ChoiceGroup/SelectedChoicesTextEntry} | ○ | ○ | ○ | ○ | ○ |
| » I will not use this again after this class | ○ | ○ | ○ | ○ | ○ |
| » This will help me in the future | ○ | ○ | ○ | ○ | ○ |
| » It is not the most important thing to me | ○ | ○ | ○ | ○ | ○ |
| » This is important but I did it because I had to | ○ | ○ | ○ | ○ | ○ |
| » It is important to think about but not always necessary | ○ | ○ | ○ | ○ | ○ |

**DA1**

Using graphs to interpret results is important

Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree

Making graphs from collected data is helpful

Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree

Interpreting graphs to understand relationships between parameters is important

Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree

I answered the previous question the way I did because ...
(Consider the entire statement when choosing your response)

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Stro disa |
|---|---|---|---|---|---|
| » This will be important when working with ${q://QID55/ChoiceGroup/SelectedChoicesTextEntry} | ○ | ○ | ○ | ○ | ○ |
| » I will not use this again after this class | ○ | ○ | ○ | ○ | ○ |
| » This will help me in the future | ○ | ○ | ○ | ○ | ○ |
| » It is not the most important thing to me | ○ | ○ | ○ | ○ | ○ |
| » This is important but I did it because I had to | ○ | ○ | ○ | ○ | ○ |
| » It is important to think about but not always necessary | ○ | ○ | ○ | ○ | ○ |

**DA2**

Using math as a tool to explain and predict is helpful

Strongly agree | Somewhat agree | Neither agree nor | Somewhat disagree | Strongly disagree

disagree

Determining patterns from my data is important

Strongly agree Somewhat agree Neither agree nor disagree Somewhat disagree Strongly disagree

Expressing confidence in my results with uncertainty is important

Strongly agree Somewhat agree Neither agree nor disagree Somewhat disagree Strongly disagree

I answered the previous question the way I did because ...
(Consider the entire statement when choosing your response)

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Stro disa |
|---|---|---|---|---|---|
| » This will be important when working with ${q://QID55/ChoiceGroup/SelectedChoicesTextEntry} | ○ | ○ | ○ | ○ | ○ |
| » I will not use this again after this class | ○ | ○ | ○ | ○ | ○ |
| » This will help me in the future | ○ | ○ | ○ | ○ | ○ |
| » It is not the most important thing to me | ○ | ○ | ○ | ○ | ○ |
| » This is important but I did it because I had to | ○ | ○ | ○ | ○ | ○ |
| » It is important to think about but not always necessary | ○ | ○ | ○ | ○ | ○ |

**DA3**

Comparing my results to the expected is important

Strongly agree Somewhat agree Neither agree nor disagree Somewhat disagree Strongly disagree

Making connections to the bigger concepts is valuable

Strongly agree Somewhat agree Neither agree nor disagree Somewhat disagree Strongly disagree

Doing math with my data in order to get my results is important

| Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|

I answered the previous question the way I did because ...
(Consider the entire statement when choosing your response)

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Stro disa |
|---|---|---|---|---|---|
| » This will be important when working with ${q://QID55/ChoiceGroup/SelectedChoicesTextEntry} | ○ | ○ | ○ | ○ | ○ |
| » I will not use this again after this class | ○ | ○ | ○ | ○ | ○ |
| » This will help me in the future | ○ | ○ | ○ | ○ | ○ |
| » It is not the most important thing to me | ○ | ○ | ○ | ○ | ○ |
| » This is important but I did it because I had to | ○ | ○ | ○ | ○ | ○ |
| » It is important to think about but not always necessary | ○ | ○ | ○ | ○ | ○ |

**EE1**

Working with the equipment is valuable

| Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|

Collecting data and taking measurements is important

| Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|

I answered the previous question the way I did because ...
(Consider the entire statement when choosing your response)

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Stro disa |
|---|---|---|---|---|---|

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Stro disa |
|---|---|---|---|---|---|
| » This will be important when working with ${q://QID55/ChoiceGroup/SelectedChoicesTextEntry} | ○ | ○ | ○ | ○ | ○ |
| » I will not use this again after this class | ○ | ○ | ○ | ○ | ○ |
| » This will help me in the future | ○ | ○ | ○ | ○ | ○ |
| » It is not the most important thing to me | ○ | ○ | ○ | ○ | ○ |
| » This is important but I did it because I had to | ○ | ○ | ○ | ○ | ○ |
| » It is important to think about but not always necessary | ○ | ○ | ○ | ○ | ○ |

**EE2**

Knowing that the uncertainty my have an impact on the experiment is important

| Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|

Working to minimize the uncertainty in my experiment is important

| Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|

I answered the previous question the way I did because ...
(Consider the entire statement when choosing your response)

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Stro disa |
|---|---|---|---|---|---|
| » This will be important when working with ${q://QID55/ChoiceGroup/SelectedChoicesTextEntry} | ○ | ○ | ○ | ○ | ○ |
| » I will not use this again after this class | ○ | ○ | ○ | ○ | ○ |
| » This will help me in the future | ○ | ○ | ○ | ○ | ○ |
| » It is not the most important thing to me | ○ | ○ | ○ | ○ | ○ |
| » This is important but I did it because I had to | ○ | ○ | ○ | ○ | ○ |
| » It is important to think about but not always necessary | ○ | ○ | ○ | ○ | ○ |

**GW1**

Bouncing ideas off of my group members is important

Strongly agree    Somewhat agree    Neither agree nor disagree    Somewhat disagree    Strongly disagree

Everyone feeling comfortable sharing their ideas in their group is important

Strongly agree    Somewhat agree    Neither agree nor disagree    Somewhat disagree    Strongly disagree

Valuing every group member's ideas is important

Strongly agree    Somewhat agree    Neither agree nor disagree    Somewhat disagree    Strongly disagree

I answered the previous question the way I did because ...
(Consider the entire statement when choosing your response)

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Stro disa |
|---|---|---|---|---|---|
| » This will be important when working with ${q://QID55/ChoiceGroup/SelectedChoicesTextEntry} | ○ | ○ | ○ | ○ | ○ |
| » I will not use this again after this class | ○ | ○ | ○ | ○ | ○ |
| » This will help me in the future | ○ | ○ | ○ | ○ | ○ |
| » It is not the most important thing to me | ○ | ○ | ○ | ○ | ○ |
| » This is important but I did it because I had to | ○ | ○ | ○ | ○ | ○ |
| » It is important to think about but not always necessary | ○ | ○ | ○ | ○ | ○ |

**GW2**

Communicating with my group about the results is important

Strongly agree    Somewhat agree    Neither agree nor    Somewhat disagree    Strongly disagree

disagree

Making decisions together as a group is important

| Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|

I answered the previous question the way I did because ...
(Consider the entire statement when choosing your response)

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Stro disa |
|---|---|---|---|---|---|
| » This will be important when working with ${q://QID55/ChoiceGroup/SelectedChoicesTextEntry} | O | O | O | O | O |
| » I will not use this again after this class | O | O | O | O | O |
| » This will help me in the future | O | O | O | O | O |
| » It is not the most important thing to me | O | O | O | O | O |
| » This is important but I did it because I had to | O | O | O | O | O |
| » It is important to think about but not always necessary | O | O | O | O | O |

**GW3**

Giving everyone in the group a chance to contribute is important

| Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|

Having help from my group if I have questions is important

| Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|

I answered the previous question the way I did because ...
(Consider the entire statement when choosing your response)

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Stro disa |
|---|---|---|---|---|---|
| » This will be important when working with ${q://QID55/ChoiceGroup/SelectedChoicesTextEntry} | ○ | ○ | ○ | ○ | ○ |
| » I will not use this again after this class | ○ | ○ | ○ | ○ | ○ |
| » This will help me in the future | ○ | ○ | ○ | ○ | ○ |
| » It is not the most important thing to me | ○ | ○ | ○ | ○ | ○ |
| » This is important but I did it because I had to | ○ | ○ | ○ | ○ | ○ |
| » It is important to think about but not always necessary | ○ | ○ | ○ | ○ | ○ |

**PE1**

Having an hypothesis when planning an experiment is important

| Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|

Having a procedure when designing an experiment is important

| Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree |
|---|---|---|---|---|

I answered the previous question the way I did because ...
(Consider the entire statement when choosing your response)

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Stro disa |
|---|---|---|---|---|---|
| » This will be important when working with ${q://QID55/ChoiceGroup/SelectedChoicesTextEntry} | ○ | ○ | ○ | ○ | ○ |
| » I will not use this again after this class | ○ | ○ | ○ | ○ | ○ |
| » This will help me in the future | ○ | ○ | ○ | ○ | ○ |
| » It is not the most important thing to me | ○ | ○ | ○ | ○ | ○ |
| » This is important but I did it because I had to | ○ | ○ | ○ | ○ | ○ |
| » It is important to think about but not always necessary | ○ | ○ | ○ | ○ | ○ |

**PE2**

Having a plan to answer my questions is important

Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree

Knowing what my goal is when planning an experiment is important

Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree

Knowing what design works best for the experiment I am planning is important

Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree

I answered the previous question the way I did because ...
(Consider the entire statement when choosing your response)

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Stro disa |
|---|---|---|---|---|---|
| » This will be important when working with ${q://QID55/ChoiceGroup/SelectedChoicesTextEntry} | ○ | ○ | ○ | ○ | ○ |
| » I will not use this again after this class | ○ | ○ | ○ | ○ | ○ |
| » This will help me in the future | ○ | ○ | ○ | ○ | ○ |
| » It is not the most important thing to me | ○ | ○ | ○ | ○ | ○ |
| » This is important but I did it because I had to | ○ | ○ | ○ | ○ | ○ |
| » It is important to think about but not always necessary | ○ | ○ | ○ | ○ | ○ |

**PE3**

Knowing what equipment I need for the experiment I am planning is important

Strongly agree | Somewhat agree | Neither agree nor | Somewhat disagree | Strongly disagree

disagree

Figuring out how to get the information I need when desiging an experiment is important

Strongly agree Somewhat agree Neither agree nor disagree Somewhat disagree Strongly disagree

Figuring out how to set up the equipment when planning an experiment is important

Strongly agree Somewhat agree Neither agree nor disagree Somewhat disagree Strongly disagree

I answered the previous question the way I did because ...
(Consider the entire statement when choosing your response)

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Stro disa |
|---|---|---|---|---|---|
| » This will be important when working with ${q://QID55/ChoiceGroup/SelectedChoicesTextEntry} | O | O | O | O | O |
| » I will not use this again after this class | O | O | O | O | O |
| » This will help me in the future | O | O | O | O | O |
| » It is not the most important thing to me | O | O | O | O | O |
| » This is important but I did it because I had to | O | O | O | O | O |
| » It is important to think about but not always necessary | O | O | O | O | O |

**UE1**

Trying out the equipment and seeing what it does is valuable

Strongly agree Somewhat agree Neither agree nor disagree Somewhat disagree Strongly disagree

Knowing what the equipment is designed to measure is valuable

Strongly agree Somewhat agree Neither agree nor disagree Somewhat disagree Strongly disagree

Knowing how to get what I need from the equipment is important

Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree

I answered the previous question the way I did because ...
(Consider the entire statement when choosing your response)

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Stro disa |
|---|---|---|---|---|---|
| » This will be important when working with ${q://QID55/ChoiceGroup/SelectedChoicesTextEntry} | ○ | ○ | ○ | ○ | ○ |
| » I will not use this again after this class | ○ | ○ | ○ | ○ | ○ |
| » This will help me in the future | ○ | ○ | ○ | ○ | ○ |
| » It is not the most important thing to me | ○ | ○ | ○ | ○ | ○ |
| » This is important but I did it because I had to | ○ | ○ | ○ | ○ | ○ |
| » It is important to think about but not always necessary | ○ | ○ | ○ | ○ | ○ |

**UE2**

Seeing how changing one component of the equipment affects something else is useful

Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree

Knowing that the equipment may have multiple uses is important

Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree

Knowing how to adapt equipment to new situations is useful

Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree

I answered the previous question the way I did because ...

(Consider the entire statement when choosing your response)

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Stro disa |
|---|---|---|---|---|---|
| » This will be important when working with ${q://QID55/ChoiceGroup/SelectedChoicesTextEntry} | ○ | ○ | ○ | ○ | ○ |
| » I will not use this again after this class | ○ | ○ | ○ | ○ | ○ |
| » This will help me in the future | ○ | ○ | ○ | ○ | ○ |
| » It is not the most important thing to me | ○ | ○ | ○ | ○ | ○ |
| » This is important but I did it because I had to | ○ | ○ | ○ | ○ | ○ |
| » It is important to think about but not always necessary | ○ | ○ | ○ | ○ | ○ |

**UE3**

Knowing how to fix the equipment when it is broken is useful

Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree

Identifying the extreme settings of the equipment is important

Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree

Knowing the limits/capabilities of the equipment is useful

Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Strongly disagree

I answered the previous question the way I did because ...
(Consider the entire statement when choosing your response)

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Stro disa |
|---|---|---|---|---|---|
| » This will be important when working with ${q://QID55/ChoiceGroup/SelectedChoicesTextEntry} | ○ | ○ | ○ | ○ | ○ |

| | Strongly agree | Somewhat agree | Neither agree nor disagree | Somewhat disagree | Stro disa |
|---|---|---|---|---|---|
| » I will not use this again after this class | ○ | ○ | ○ | ○ | ○ |
| » This will help me in the future | ○ | ○ | ○ | ○ | ○ |
| » It is not the most important thing to me | ○ | ○ | ○ | ○ | ○ |
| » This is important but I did it because I had to | ○ | ○ | ○ | ○ | ○ |
| » It is important to think about but not always necessary | ○ | ○ | ○ | ○ | ○ |

**End Block**

Do you see yourself as a physics person?

| No, not at all 1 | 2 | 3 | 4 | 5 | Yes, very much 6 |
|---|---|---|---|---|---|

While taking this survey I was most frequently thinking of myself as a member of this community (select all that apply)

Science student

Person in my major

A person with a future in ${q://QID223/ChoiceGroup/SelectedChoices}

An aware citizen

Curious person

${q://QID226/ChoiceTextEntryValue/4}

While taking the survey did you find the options provided under 'I answered the previous question the way I did because' sufficiently covered your own reasoning?

Yes

Sometimes

No

If you believe some options were missing please include them below

Is there anything you would like to tell us about the experience of taking this survey?

# APPENDIX K

## DISTRIBUTION OF VERSION 2 RESPONSES

This appendix contains the distributions of responses to all questions from Version 2 of the survey (Chapter 6 Sec. 6.4).

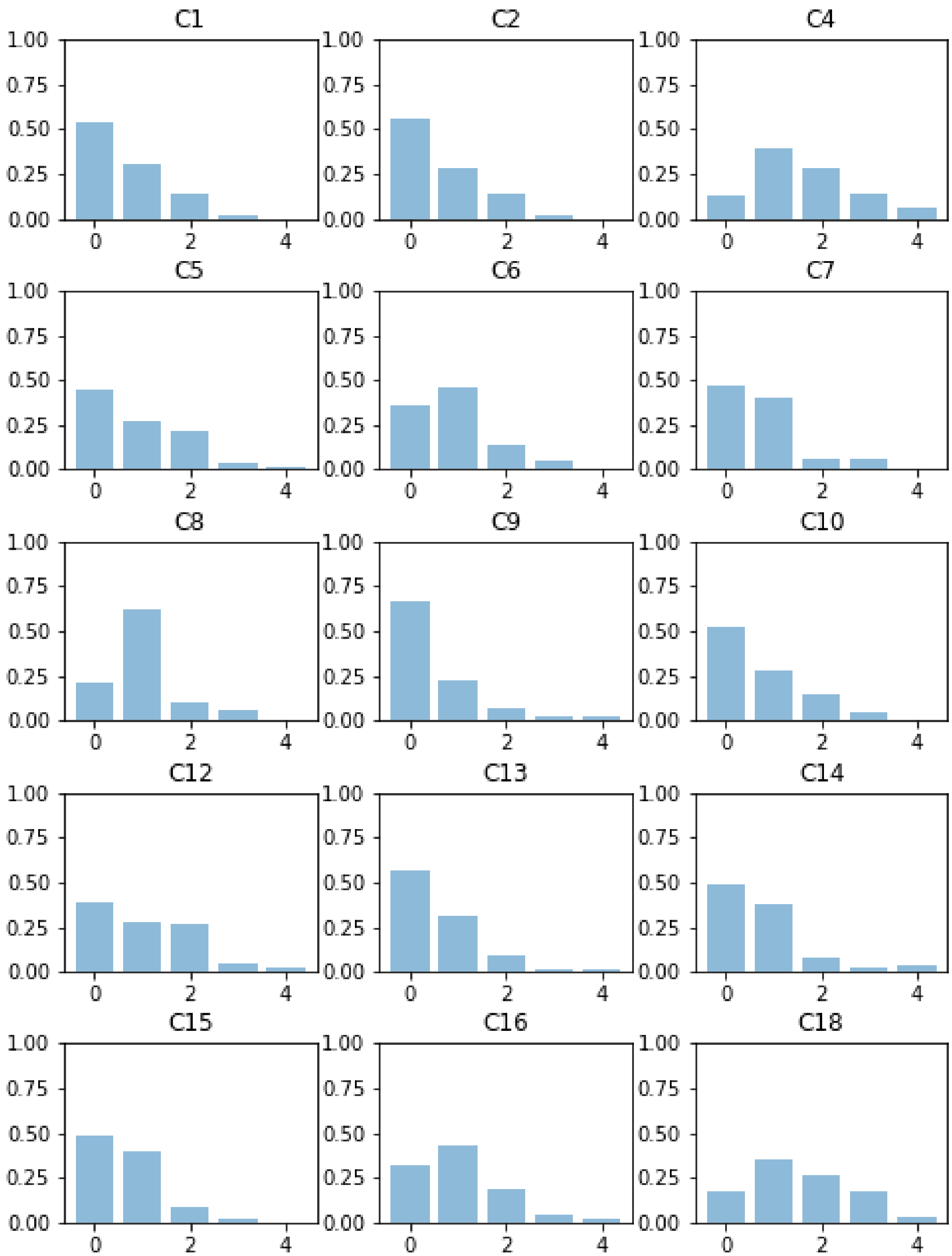



Figure K.1: Distributions of responses to Communicating questions in Version 2 of the survey. The distributions are all normalized to one. On the x-axis: 0 is Strongly agree, 1 is Somewhat agree, 2 is Niether agree nor disagree, 3 is Somewhat disagree, and 4 is Strongly disagree. The reference number of the question is in the title (see Appendix G for questions).

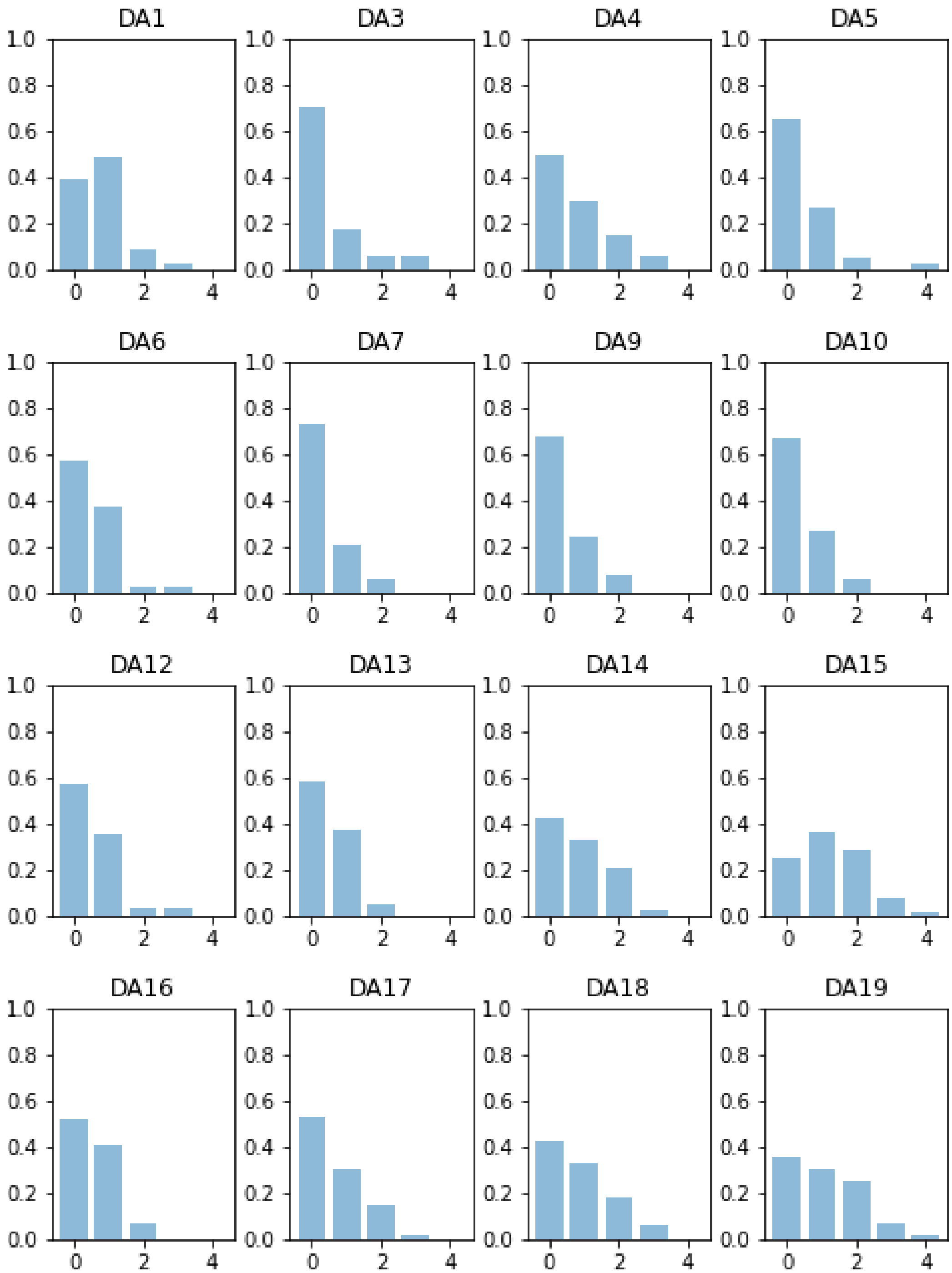



Figure K.2: Distributions of responses to Data Analysis questions in Version 2 of the survey. The distributions are all normalized to one. On the x-axis: 0 is Strongly agree, 1 is Somewhat agree, 2 is Niether agree nor disagree, 3 is Somewhat disagree, and 4 is Strongly disagree. The reference number of the question is in the title (see Appendix G for questions).

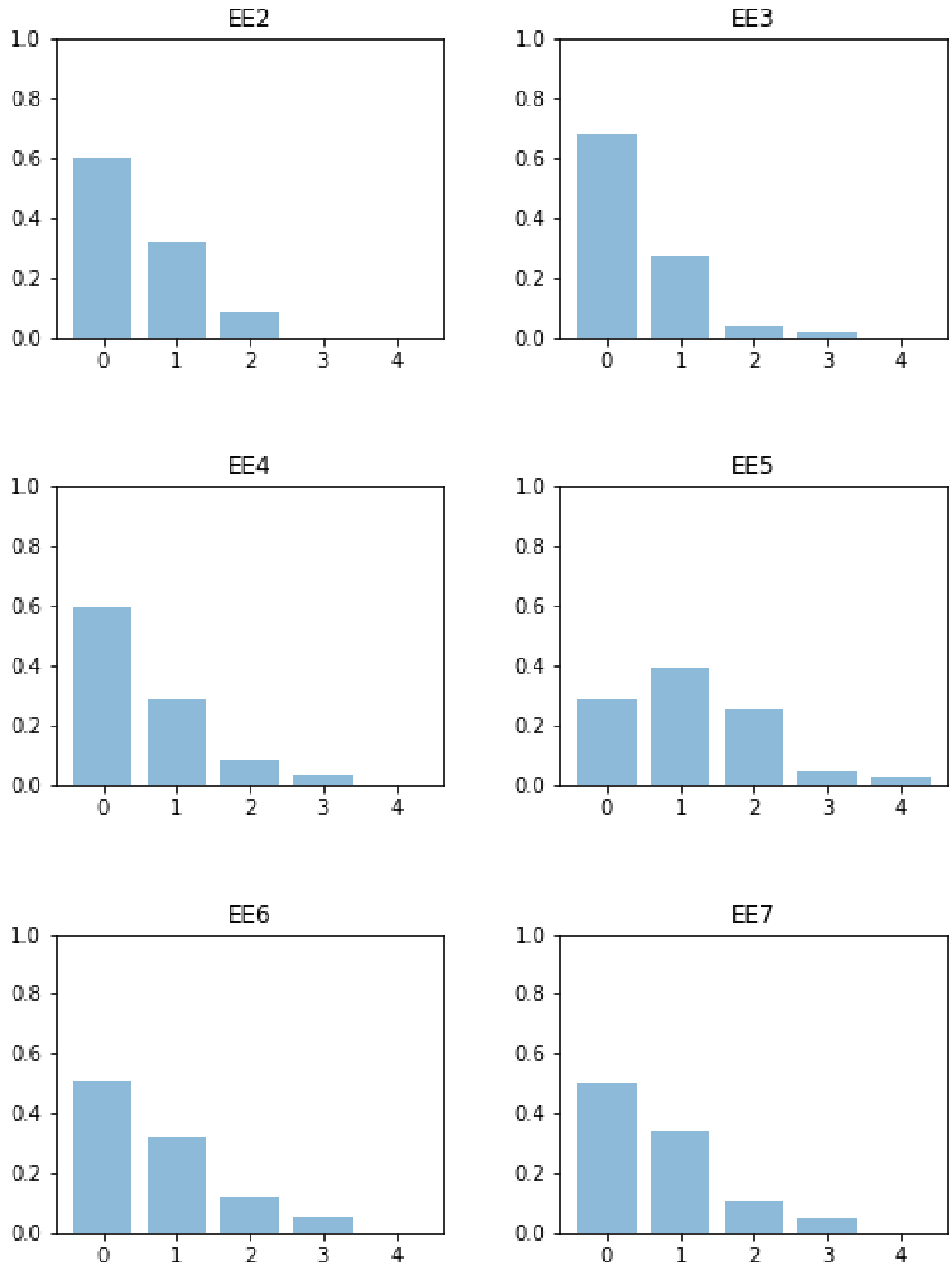



Figure K.3: Distributions of responses to Executing Experiments questions in Version 2 of the survey. The distributions are all normalized to one. On the x-axis: 0 is Strongly agree, 1 is Somewhat agree, 2 is Niether agree nor disagree, 3 is Somewhat disagree, and 4 is Strongly disagree. The reference number of the question is in the title (see Appendix G for questions).

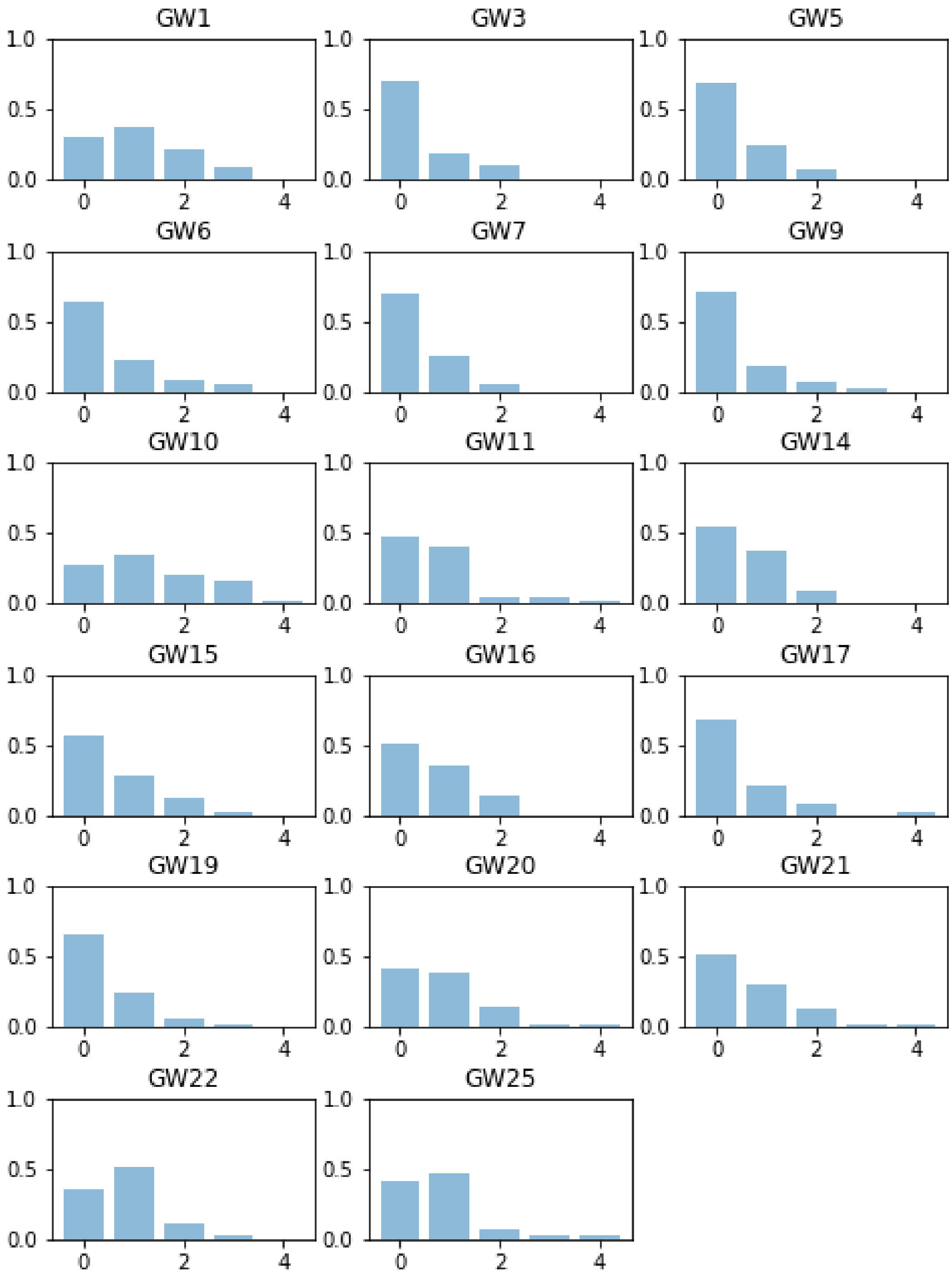



Figure K.4: Distributions of responses to Group Work questions in Version 2 of the survey. The distributions are all normalized to one. On the x-axis: 0 is Strongly agree, 1 is Somewhat agree, 2 is Niether agree nor disagree, 3 is Somewhat disagree, and 4 is Strongly disagree. The reference number of the question is in the title (see Appendix G for questions).

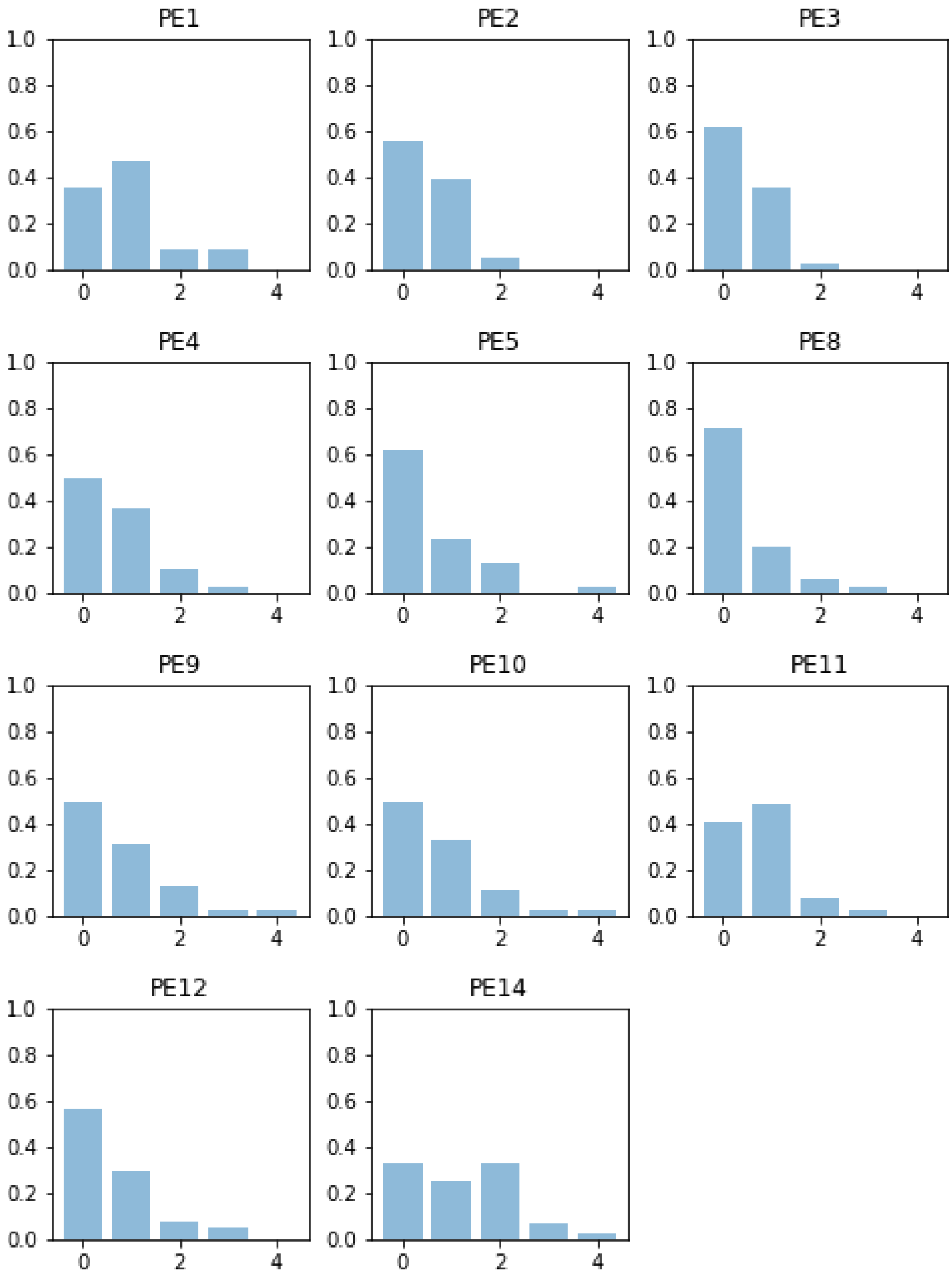



Figure K.5: Distributions of responses to Planning Experiments questions in Version 2 of the survey. The distributions are all normalized to one. On the x-axis: 0 is Strongly agree, 1 is Somewhat agree, 2 is Niether agree nor disagree, 3 is Somewhat disagree, and 4 is Strongly disagree. The reference number of the question is in the title (see Appendix G for questions).

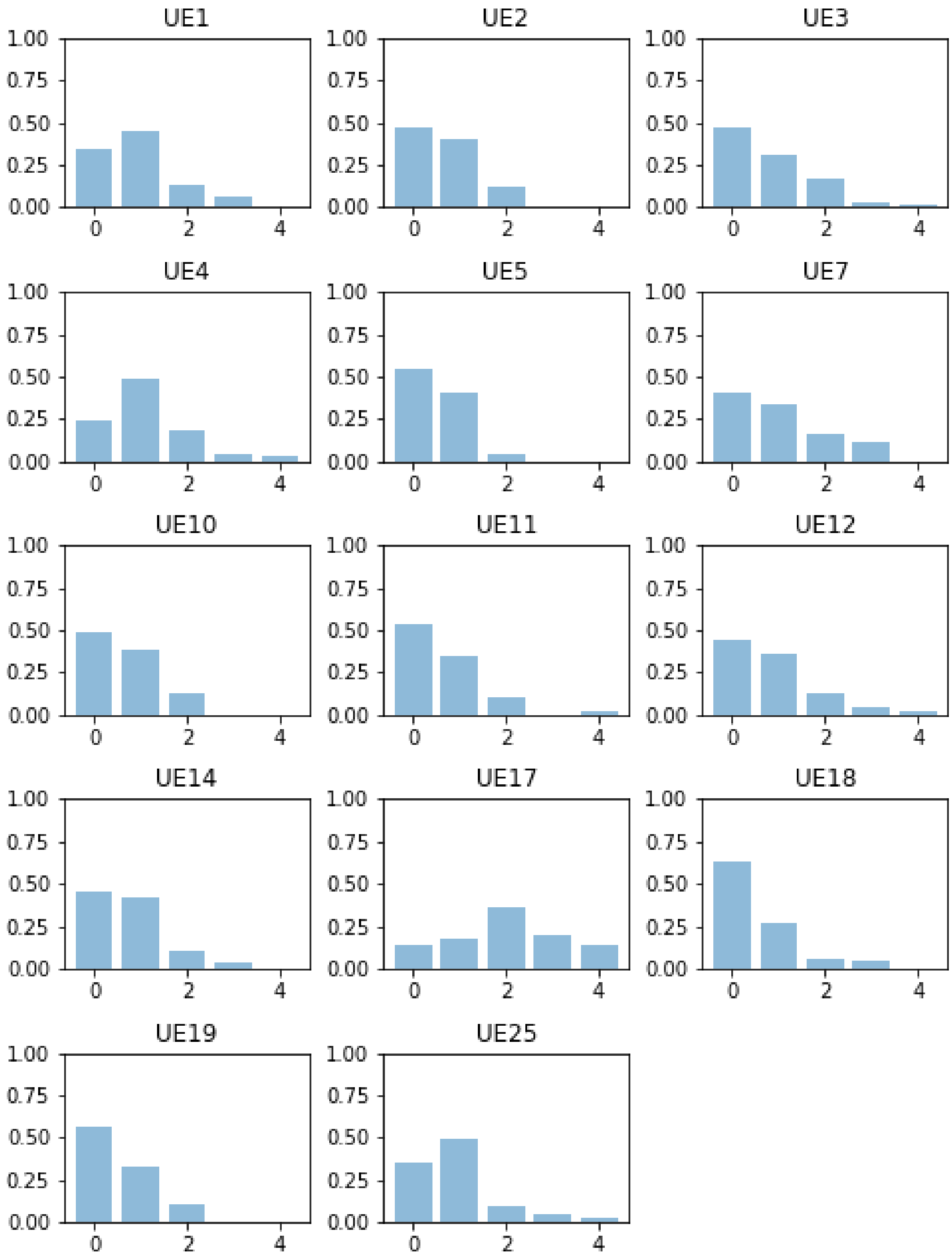



Figure K.6: Distributions of responses to Understanding Equipment questions in Version 2 of the survey. The distributions are all normalized to one. On the x-axis: 0 is Strongly agree, 1 is Somewhat agree, 2 is Niether agree nor disagree, 3 is Somewhat disagree, and 4 is Strongly disagree. The reference number of the question is in the title (see Appendix G for questions).

# APPENDIX L

## DISTRIBUTION OF VERSION 3 RESPONSES

This appendix contains the distributions of responses to all questions from Version 3 of the survey (Chapter 6 Sec. 6.5).

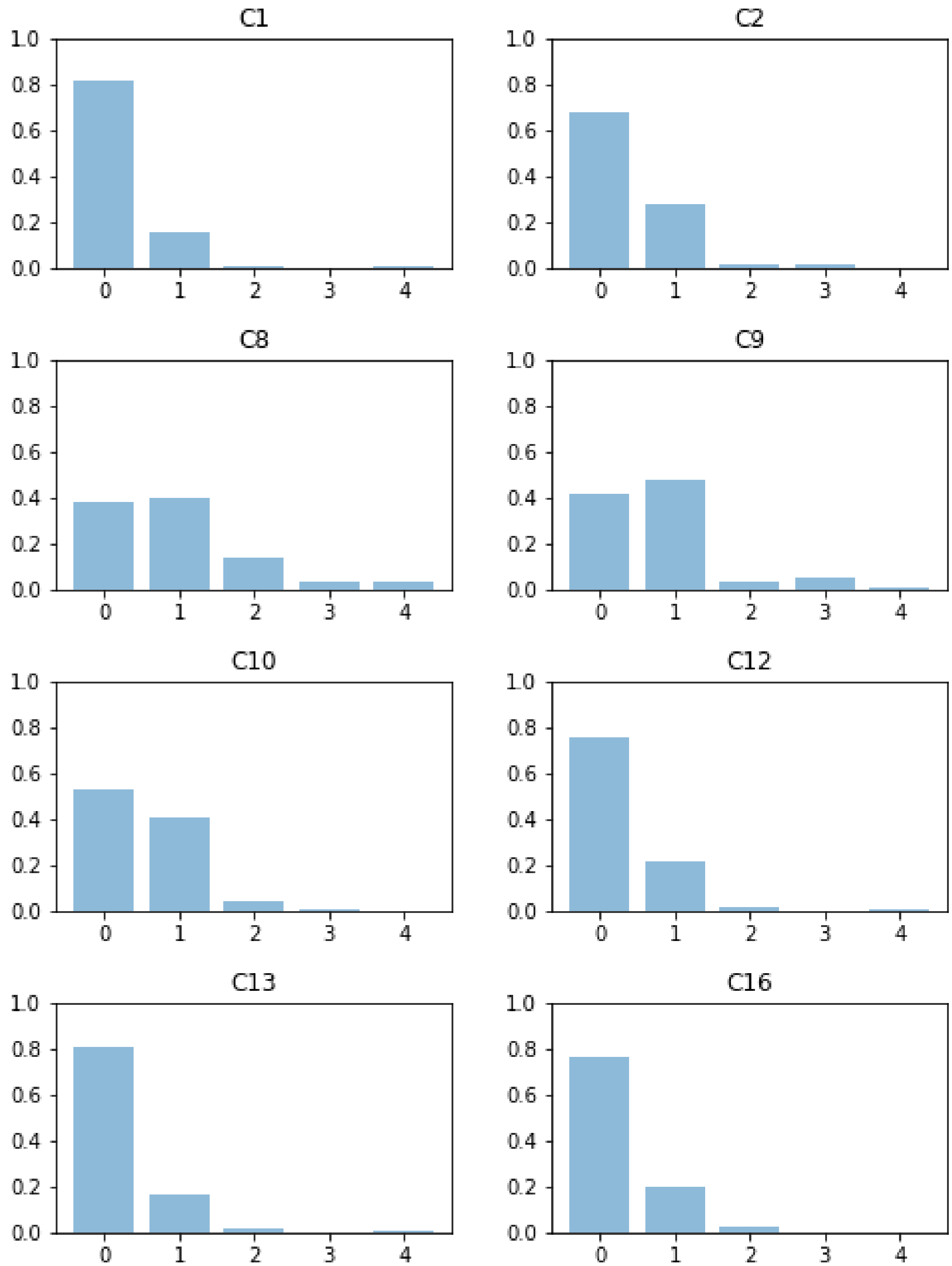



Figure L.1: Distributions of responses to Communicating questions in Version 3 of the survey. The distributions are all normalized to one. On the x-axis: 0 is Strongly agree, 1 is Somewhat agree, 2 is Niether agree nor disagree, 3 is Somewhat disagree, and 4 is Strongly disagree. The reference number of the question is in the title (see Appendix G for questions).

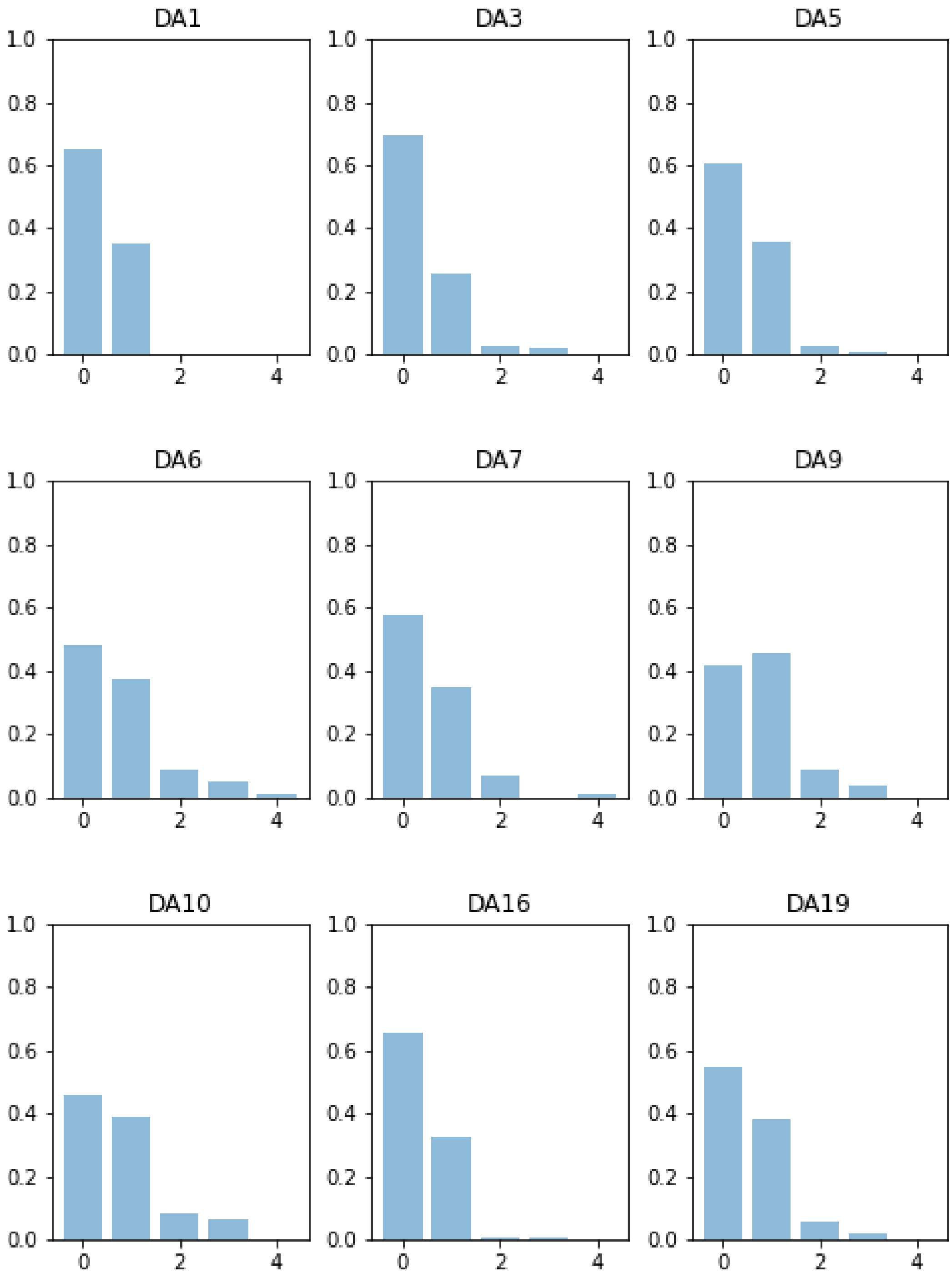



Figure L.2: Distributions of responses to Data Analysis questions in Version 3 of the survey. The distributions are all normalized to one. On the x-axis: 0 is Strongly agree, 1 is Somewhat agree, 2 is Niether agree nor disagree, 3 is Somewhat disagree, and 4 is Strongly disagree. The reference number of the question is in the title (see Appendix G for questions).

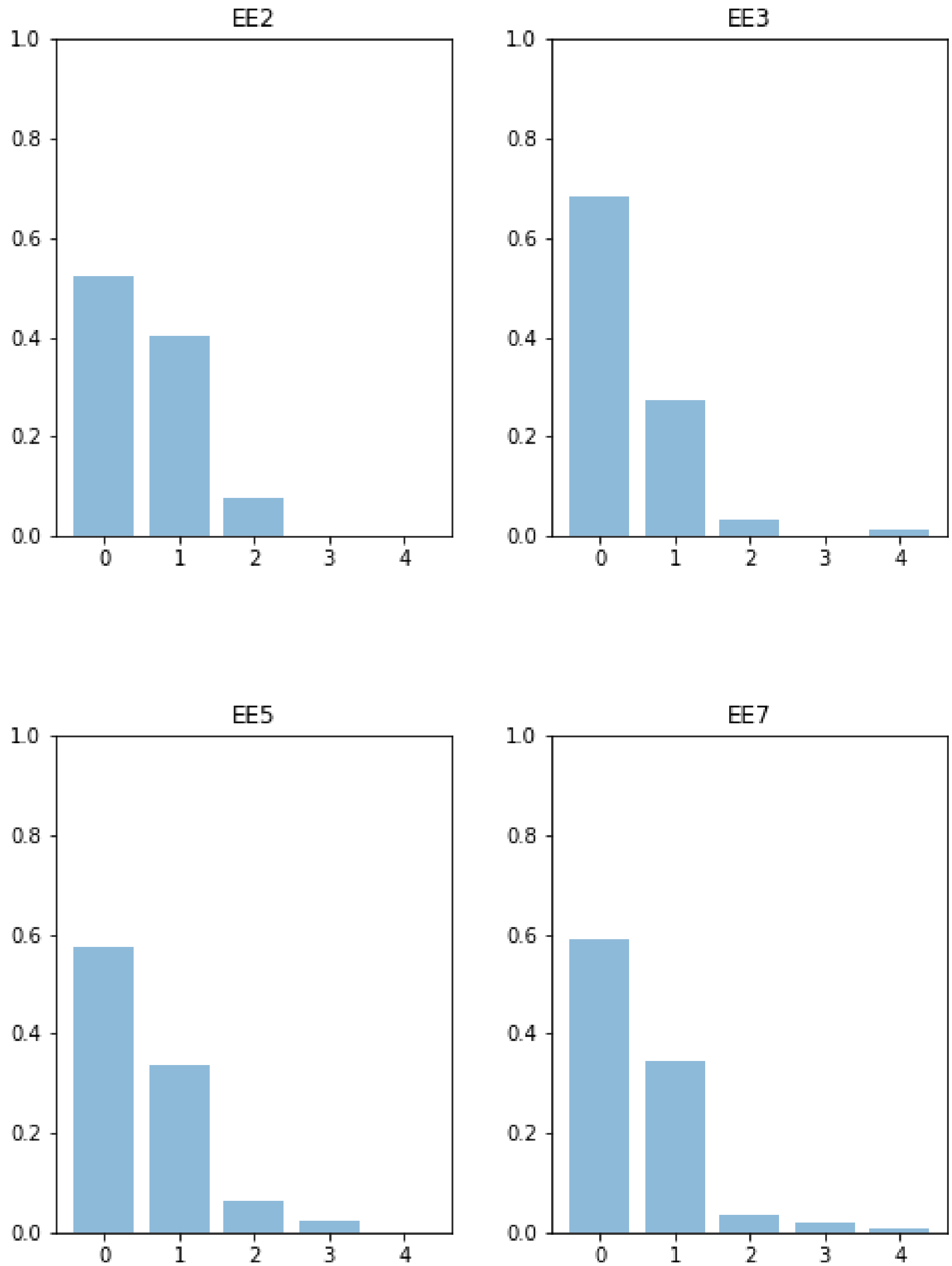



Figure L.3: Distributions of responses to Executing Experiments questions in Version 3 of the survey. The distributions are all normalized to one. On the x-axis: 0 is Strongly agree, 1 is Somewhat agree, 2 is Niether agree nor disagree, 3 is Somewhat disagree, and 4 is Strongly disagree. The reference number of the question is in the title (see Appendix G for questions).

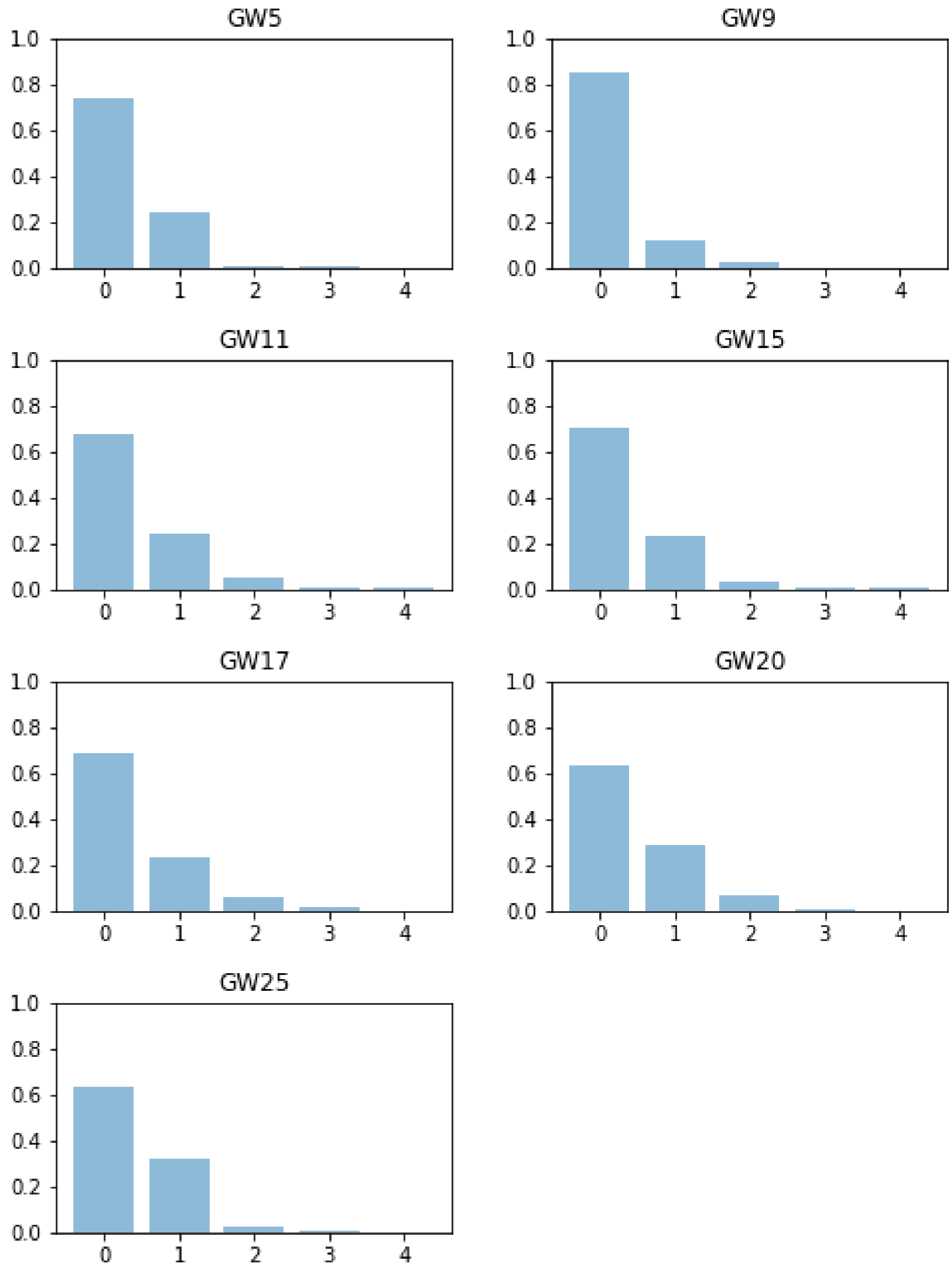



Figure L.4: Distributions of responses to Group Work questions in Version 3 of the survey. The distributions are all normalized to one. On the x-axis: 0 is Strongly agree, 1 is Somewhat agree, 2 is Niether agree nor disagree, 3 is Somewhat disagree, and 4 is Strongly disagree. The reference number of the question is in the title (see Appendix G for questions).

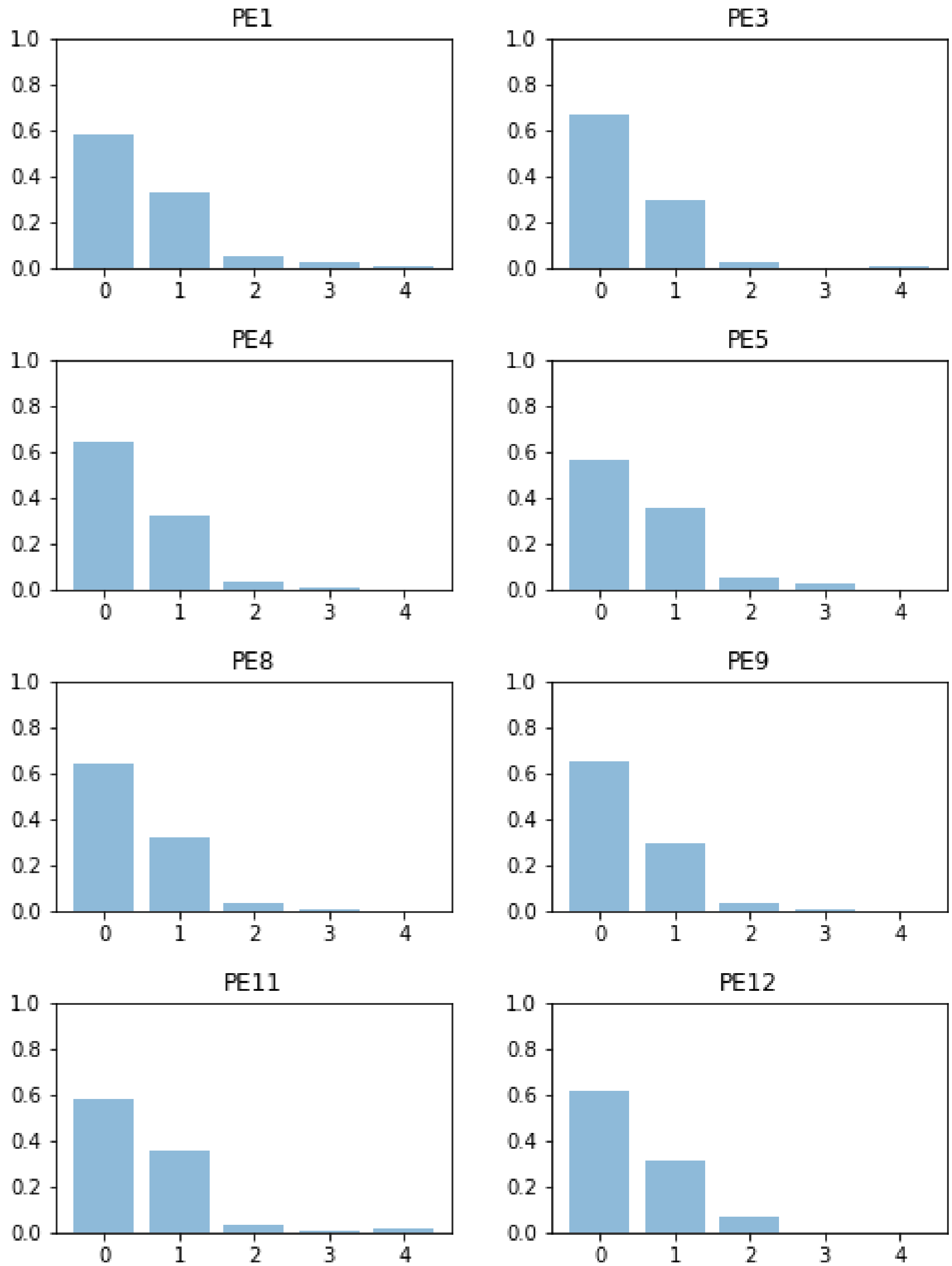



Figure L.5: Distributions of responses to Planning Experiments questions in Version 3 of the survey. The distributions are all normalized to one. On the x-axis: 0 is Strongly agree, 1 is Somewhat agree, 2 is Niether agree nor disagree, 3 is Somewhat disagree, and 4 is Strongly disagree. The reference number of the question is in the title (see Appendix G for questions).

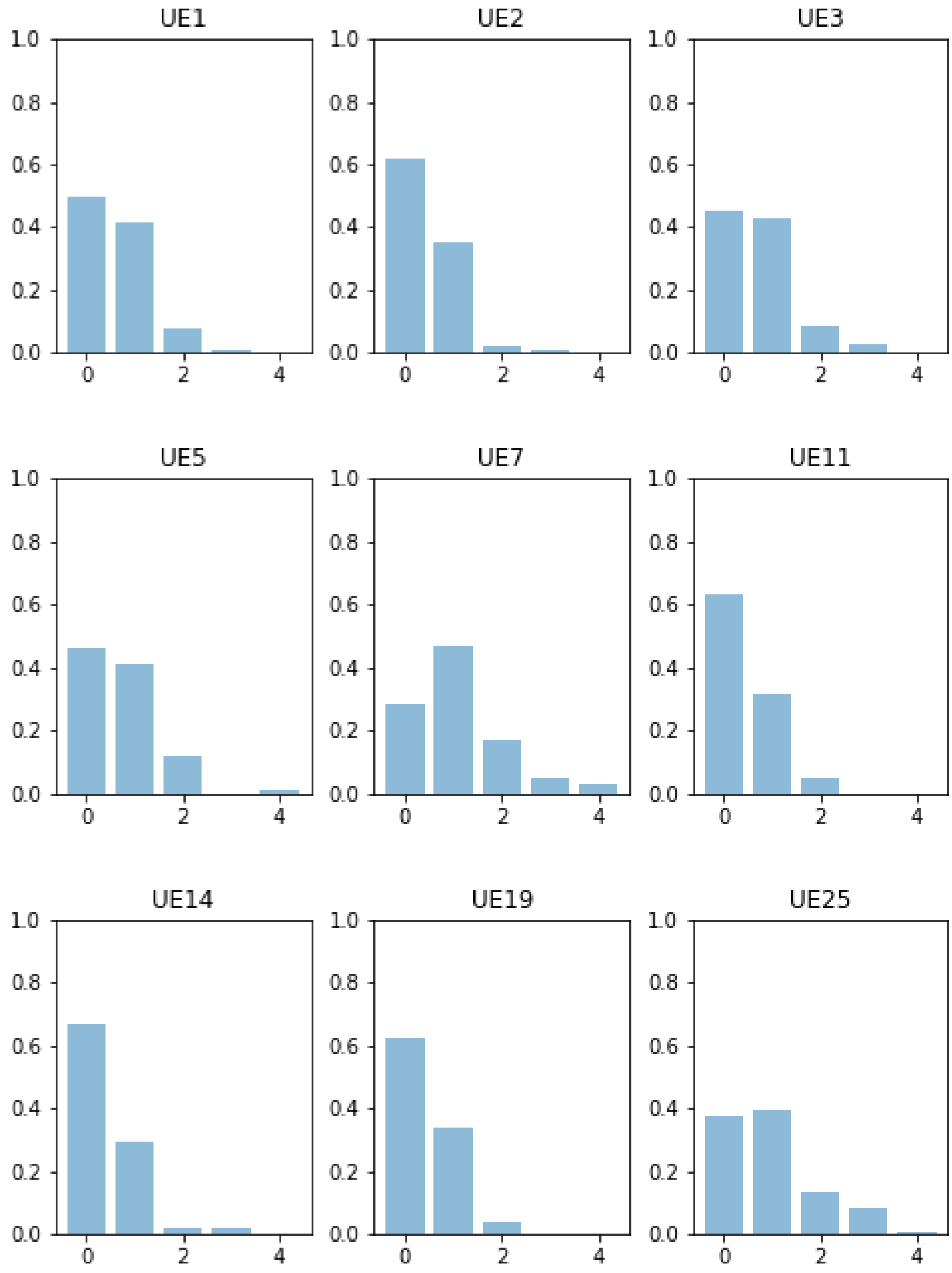



Figure L.6: Distributions of responses to Understanding Equipment questions in Version 3 of the survey. The distributions are all normalized to one. On the x-axis: 0 is Strongly agree, 1 is Somewhat agree, 2 is Niether agree nor disagree, 3 is Somewhat disagree, and 4 is Strongly disagree.The reference number of the question is in the title (see Appendix G for questions).

# APPENDIX M

## FINAL SURVEY VERSION

This appendix contains the final version of the Practice-Based Identity Survey, see Table M.1.

Table M.1: Questions for the final version of the survey

**Practice Questions**

| Reference | Question |
|---|---|
| C1 | Explaining what I found is important |
| C8 | Presenting what I did is important |
| C9 | Communicating my results by writing in my lab notebook is helpful |
| C12 | Being able to communicate my understanding is important |
| DA1 | Comparing my results to the expected is important |
| DA6 | Making graphs from collected data is helpful |
| DA10 | Using math as a tool to explain and predict is helpful |
| DA16 | Determining patterns from my data is important |
| DA19 | Expressing confidence in my results with uncertainty is important |
| EE2 | Working with the equipment is valuable |
| EE3 | Collecting data and taking measurements is important |
| EE7 | Working to minimize the uncertainty in my experiment is important |
| GW9 | Everyone feeling comfortable sharing their ideas in their group is important |
| GW15 | Having help from my group if I have questions is important |
| GW17 | Bouncing ideas off of my group members is important |
| GW20 | Making decisions together as a group is important |
| PE4 | Knowing what design works best for the experiment I am planning is important |
| PE9 | Figuring out how to set up the equipment when planning an experiment is important |
| PE11 | Having an hypothesis when planning an experiment is important |
| UE1 | Knowing that the equipment may have multiple uses is important |
| UE2 | Knowing how to adapt equipment to new situations is useful |
| UE10 | Knowing how the equipment works is important |
| UE19 | Knowing the limits/capabilities of the equipment is useful |
| UE25 | Knowing how to fix the equipment when it is broken is useful |

**Identity Reasoning Questions**

| Label | Question |
|---|---|
| LT2 | I will not use this again after this class |
| LT3 | This will help me in the future |
| NE1 | It is not the most important thing to me |
| NE2 | This is important but I did it because I had to |
| NE3 | It is important to think about but not always necessary |

# BIBLIOGRAPHY

# BIBLIOGRAPHY


[1] Benjamin M. Zwickl, Takako Hirokawa, Noah Finkelstein, and H. J. Lewandowski. Epistemology and expectations survey about experimental physics: Development and initial results. *Physical Review Special Topics-Physics Education Research*, 10(1):010120, 2014.

[2] B. R. Wilcox and H. J. Lewandowski. Developing skills versus reinforcing concepts in physics labs: Insight from a survey of students' beliefs about experimental physics. *Physical Review Physics Education Research*, 13(1):010108, 2017.

[3] Eleanor W. Close, Jessica Conn, and Hunter G. Close. Learning Assistants' Development of Physics (Teacher) Identity. *2013 Physics Education Research Conference Proceedings*, pages 89–92, 2013.

[4] Etienne Wenger. Identity in practice. In *Communities of Practice Learning, Meaning, and Identity*, chapter 6, pages 149–163. Cambridge University Press, 1999.

[5] AAPT. AAPT Recommendations for the Undergraduate Physics Laboratory Curriculum. *Report*, page 29, 2014.

[6] Sidney Rosen. A History of the Physics Laboratory in the American Public High School (to 1910). *American Journal of Physics*, 22(4):194–204, 1953.

[7] Avi Hofstein and Vincent N. Lunetta. The Role of the Laboratory in Science Teaching: Neglected Aspects of Research. *Review of Educational Research*, 52(2):201–217, 1982.

[8] C. R. Mann. The Present Condition of Physics Teaching in the United States. In *Broad lines in science teaching*, pages 227–238. 1910.

[9] G. R. Bates. The role of the laboratory in secondary school science programs. *What research says to the science teacher*, 1:55–82, 1978.

[10] Carl Wieman and N. G. Holmes. Measuring the impact of an instructional laboratory on the learning of introductory physics. *American Journal of Physics*, 83(11):972–978, 2015.

[11] N. G. Holmes, Jack Olsen, James L. Thomas, and Carl E. Wieman. Value added or misattributed? a multi-institution study on the educational benefit of labs for reinforcing physics content. *Physical Review Physics Education Research*, 13(1):010129, 2017.

[12] National Research Council. *A framework for K-12 Science Education*. 2012.

[13] Michael P. Freedman. Relationship among laboratory instruction, attitude toward science, and achievement in science knowledge. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching*, 34(4):343–357, 1997.

[14] Elaine Seymour, Anne-Barrie Hunter, Sandra L. Laursen, and Tracee DeAntoni. Establishing the benefits of research experiences for undergraduates in the sciences: First findings from a three-year study. *Science education*, 88(4):493–534, 2004.

[15] Remziye Ergül, Yeter Şımşeklı, Sevgül Çaliş, Zehra Özdılek, Şirin Göçmençelebı, and Meral Şanli. The Effects of Inquiry-Based Science Teaching on Elementary School Students' Science Process Skills and Science Attitudes. *Bulgarian Journal of Science and Education Policy*, 5(1):48–68, 2011.

[16] Melinda Harrison, David Dunbar, Lisa Ratmansky, Kimberly Boyd, and David Lopatto. Classroom-based science research at the introductory level: Changes in career choices and attitude. *CBE Life Sciences Education*, 10(3):279–286, 2011.

[17] Anja Bechmann and Stine Lomborg. Relationship among laboratory instruction, attitude toward science, and achievement in science knowledge. *Journal of Research in Science Teaching*, 34(4):343–357, 1997.

[18] Olga Pierrakos, Thi Kay Beam, Jamie Constantz, Aditya Johri, and Robin Anderson. On the development of a professional identity: Engineering persisters vs engineering switchers. *Proceedings - Frontiers in Education Conference, FIE*, (2):1–6, 2009.

[19] Zahra Hazari, Gerhard Sonnert, Philip M. Sadler, and Marie-Claire Shanahan. Connecting high school physics experiences, outcome expectations, physics identity, and physics career choice: A gender study. *Journal of Research in Science Teaching*, 47(8):978–1003, 2010.

[20] H. B. Carlone and A. Johnson. Understanding the Science Experiences of Successful Women of Color: Science Identity as an Analytic Lens. *Journal of Research in Science Teaching*, 44(8):1269–1291, 2007.

[21] Eleanor W. Close, Jessica Conn, and Hunter G. Close. Becoming physics people: Development of integrated physics identity through the Learning Assistant experience. *Physical Review Physics Education Research*, 12(1):010109, 2016.

[22] Alexander Smith and Edwin Herbert Hall. *The teaching of chemistry and physics in the secondary school*. Longmans, Green, and Company, 1902.

[23] John Dewey. *How We Think*. D. C. Heath and Co. Publishers, 1910.

[24] Lee S Shulman and Pinchas Tamir. Research on teaching in the natural sciences. *Second handbook of research on teaching*, pages 1098–1148, 1973.

[25] Paul DeHart Hurd. *New directions in teaching secondary school science*. Rand McNally, 1969.

[26] Vincent N. Lunetta and Pinchas Tamir. An analysis of laboratory activities in two modern science curricula: Project physics and pssc. 1978.

[27] Joseph Jackson Schwab. *The Teaching of Science. The Teaching of Science as Enquiry.[By] JJ Schwab. Elements in a Strategy for Teaching Science in the Elementary School.[By] Paul F. Brandwein*. Harvard University Press, 1962.

[28] Jack Cassels Jeffrey. Identification of objectives of the chemistry laboratory and development of means for measuring student achievement of some of these objectives. 1968.

[29] R. F. Kempa and J. E. Ward. The effect of different modes of task orientation on observational attainment in practical chemistry. *Journal of Research in Science Teaching*, 12(1):69–76, 1975.

[30] Pinchas Tamir. An Inquiry Oriented Laboratory Examination. *Journal of Educational Measurement*, 11(1):25–33, 1974.

[31] O. Roger Anderson. *The experience of science: A new perspective for laboratory teaching*. Teachers College Press, Teachers College, Columbia University, 1976.

[32] National Research Council. *National Science Education Standards*. 1996.

[33] National Research Council. *Inquiry and the National Science Education Standards*. 2000.

[34] Eugenia Etkina, Sahana Murthy, and Xueli Zou. Using introductory labs to engage students in experimental design. *American Journal of Physics*, pages 979–986, 2006.

[35] Eugenia Etkina, Alan Van Heuvelen, Suzanne White-Brahmia, David T. Brookes, Michael Gentile, Sahana Murthy, David Rosengrant, and Aaron Warren. Scientific abilities and their assessment. *Physical Review Special Topics - Physics Education Research*, 2(2):1–15, 2006.

[36] Kirsty Dunnett, M. N. Gorman, and P. A. Bartlett. Assessing first-year undergraduate physics students' laboratory practices: seeking to encourage research behaviours. *European journal of physics*, 40(1):015702, 2018.

[37] H. J. Lewandowksi, Daniel Bolton, and Benjamin Pollard. Initial Impacts of the transformation of a large Introductory lab course focused on developing experimental skills and expert epistemology. *Physics Education Research Conference Proceedings*, page submitted, 2018.

[38] Benjamin M. Zwickl, Noah Finkelstein, and Heather J. Lewandowski. The process of transforming an advanced lab course: Goals, curriculum, and assessments. *American Journal of Physics*, 81(1):63–70, 2013.

[39] H. J. Lewandowski and Noah Finkelstein. Redesigning a junior-level electronics course to support engagement in scientific practices. *Physics Education Research Conference Proceedings*, pages 191–194, 2015.

[40] Kelsey Marie Funkhouser, William Martinez, Rachel Henderson, and Marcos D. Caballero. Design, analysis, tools, and apprenticeship (data) lab. *European Journal of Physics*, 2019.

[41] Carl Wieman. *Improving how universities teach science: lessons from the science education initiative*. Harvard University Press, 2017.

[42] Saalih Allie, Andy Buffler, Bob Campbell, and Fred Lubben. First-year physics students' perceptions of the quality of experimental measurements. *International Journal of Science Education*, 20(4):447–459, 1998.

[43] Andy Buffler, Saalih Allie, and Fred Lubben. The development of first year physics students' ideas about measurement in terms of point and set paradigms. *International Journal of Science Education*, 23(11):1137–1156, 2001.

[44] Cole Walsh, Katherine N. Quinn, C. Wieman, and N. G. Holmes. Quantifying critical thinking: Development and validation of the physics lab inventory of critical thinking. *Physical Review Physics Education Research*, 15(1):010135, 2019.

[45] Eugenia Etkina, Anna Karelina, Maria Ruibal-villasenor, David Rosengrant, Rebecca Jordan, and Cindy E. Hmelo-silver. Design and Reflection Help Students Develop Scientific Abilities: Learning in Introductory Physics Laboratories. *The Journal of Learning Sciences*, 2010.

[46] Eugenia Etkina and Gorazd Planinšič. Defining and developing "critical thinking" through devising and testing multiple explanations of the same phenomenon. *The Physics Teacher*, 53(7):432–437, 2015.

[47] Anna Karelina and Eugenia Etkina. Acting like a physicist: Student approach study to experimental design. *Physical Review Special Topics-Physics Education Research*, 3(2):020106, 2007.

[48] Kevin D. O'Neill and Joseph L. Polman. Why educate "little scientists?" examining the potential of practice-based scientific literacy. *Journal of research in Science Teaching*, 41(3):234–266, 2004.

[49] N. G. Holmes, Carl E. Wieman, and D. A. Bonn. Teaching critical thinking. *Proceedings of the National Academy of Sciences*, 112(36):11199–11204, 2015.

[50] Anna Sfard and Anna Prusak. Telling identities: In search of an analytic tool for investigating learning as a culturally shaped activity. *Educational researcher*, 34(4):14–22, 2005.

[51] James Paul Gee. Identity as an Analytic Lens for Research in Education. *Review of Research in Education*, 25(1):99–125, 2000.

[52] Jean Lave and Etienne Wenger. *Situated learning: Legitimate peripheral participation*. Cambridge university press, 1991.

[53] Paul W. Irving and Eleanor C. Sayre. Physics identity development: A snapshot of the stages of development of upper-level physics students. *Journal of the Scholarship of Teaching & Learning*, 13(4):68–84, 2013.

[54] Paul W. Irving and Eleanor C. Sayre. Upper-Level Physics Students ' Perceptions of Physicists. *Proceedings of the International Conference of the Learning Sciences*, pages 1513–1514, 2014.

[55] Paul W. Irving and Eleanor C. Sayre. Becoming a physicist: The roles of research, mindsets, and milestones in upper-division student perceptions. *Physical Review Special Topics - Physics Education Research*, 11(2):1–21, 2015.

[56] Paul W. Irving and Eleanor C. Sayre. Identity statuses in upper-division physics students. *Cultural Studies of Science Education*, 11(4):1–46, 2016.

[57] Paul W. Irving and Eleanor C. Sayre. Conditions for building a community of practice in an advanced physics laboratory. *Physical Review Special Topics - Physics Education Research*, 10(1):1–16, 2014.

[58] Dedra Demaree and Sissi Li. Promoting productive communities of practice: An instructor's perspective. *AIP Conference Proceedings*, 1179:125–128, 2009.

[59] Leema K. Berland. Explaining variation in how classroom communities adapt the practice of scientific argumentation. *Journal of the Learning Sciences*, 20(4):625–664, 2011.

[60] Joseph Kozminski, Heather Lewandowski, Nancy Beverly, Steve Lindaas, Duane Deardorff, Ann Reagan, Richard Dietz, Randy Tagg, Jeremiah Williams, Robert Hobbs, et al. Aapt recommendations for the undergraduate physics laboratory curriculum. *American Association of Physics Teachers*, page 29, 2014.

[61] Steve Olson and Donna Gerardi Riordan. Engage to Excel: Producing One Million Additional College Graduates with Degrees in Science, Technology, Engineering, and Mathematics. Report to the President. *Executive Office of the President*, 2012.

[62] Eugenia Etkina and A. V. Heuvelen. Investigative Science Learning Environment: Using the processes of science and cognitive strategies to learn physics. 2001.

[63] Robert Beichner. The student-centered activities for large enrollment undergraduate programs (scale-up) project. In *Research-Based Reform of University Physics*, volume 1. April 2007.

[64] Jack M. Wilson. The CUPLE physics studio. *The Physics Teacher*, 32(9):518–523, 1994.

[65] Melissa Dancy and Charles Henderson. Barriers and promises in stem reform. In *National Academies of Science Promising Practices Workshop*, 2008.

[66] Stephanie V. Chasteen, Katherine K. Perkins, Paul D. Beale, Steven J. Pollock, and Carl E. Wieman. A thoughtful approach to instruction: Course transformation for the rest of us. *Journal of College Science Teaching*, 40(4):24, 2011.

[67] Stephanie V. Chasteen, Steven J. Pollock, Rachel E. Pepper, and Katherine K. Perkins. Transforming the junior level: Outcomes from instruction and research in E&M. *Physical Review Special Topics-Physics Education Research*, 8(2):020107, 2012.

[68] John Biggs. Enhancing teaching through constructive alignment. *Higher Education*, 32(3):347–364, 1996.

[69] Valerie Otero, Steven Pollock, and Noah Finkelstein. A physics department's role in preparing physics teachers: The Colorado learning assistant model. *American Journal of Physics*, 78(11):1218–1224, 2010.

[70] Paul W. Irving, Michael J. Obsniuk, and Marcos D. Caballero. $P^3$: a practice focused learning environment. *European Journal of Physics*, 38(5):055701, 2017.

[71] Bethany R. Wilcox and H. J. Lewandowski. Students' epistemologies about experimental physics: Validating the colorado learning attitudes about science survey for experimental physics. *Physical Review Physics Education Research*, 12(1):010123, 2016.

[72] Dehui Hu, Benjamin M. Zwickl, Bethany R. Wilcox, and H. J. Lewandowski. Qualitative investigation of students' views about experimental physics. *Physical Review Physics Education Research*, 13(2):020134, 2017.

[73] Bethany R. Wilcox and H. J. Lewandowski. A summary of research-based assessment of students' beliefs about the nature of experimental physics. *American Journal of Physics*, 86(3):212–219, 2018.

[74] Wendy K. Adams, Katherine K. Perkins, Noah S. Podolefsky, Michael Dubson, Noah D. Finkelstein, and Carl E. Wieman. New instrument for measuring student beliefs about physics and learning physics: The colorado learning attitudes about science survey. *Physical review special topics-physics education research*, 2(1):010101, 2006.

[75] Angela Calabrese Barton and Kimberley Yang. The culture of power and science education : Learning from Miguel. *Journal of Research in Science Teaching*, 2000.

[76] Benjamin M. Zwickl, Noah Finkelstein, and H. J. Lewandowski. Incorporating learning goals about modeling into an upper-division physics laboratory experiment. *American Journal of Physics*, 82(9):876–882, 2014.

[77] Natasha Grace Holmes. Structured quantitative inquiry labs : developing critical thinking in the introductory physics laboratory. *PhD Thesis*, (December):1–127, 2014.

[78] N. G. Holmes, Jack Olsen, James L. Thomas, and Carl E. Wieman. Value added or misattributed? A multi-institution study on the educational benefit of labs for reinforcing physics content. *Physical Review Physics Education Research*, 13(1):1–12, 2017.

[79] Jacob T. Stanley and H. J. Lewandowski. Lab notebooks as scientific communication: Investigating development from undergraduate courses to graduate research. *Physical Review Physics Education Research*, 12(2):1–11, 2016.

[80] Jacob T. Stanley, Dimitri R. Dounas-Frazer, Laura Kiepura, and H. J. Lewandowski. Investigating student ownership of projects in an upper-division physics lab course. *Physics Education Research Conference Proceedings*, pages 1–4, 2016.

[81] D.H. Putri, E. Risdianto, S. Sutarno, and D. Hamdani. The development of cooperative problem solving physics laboratory model on simple pendulum concept. *Journal of Physics: Conference Series*, 1157:032005, 2019.

[82] Bobby Cerini, Ian Murray, and Michael Reiss. Student review of the science curriculum: Major findings. 2003.

[83] Jacob Cohen. A coefficient of agreement for nominal scales. *Educational and psychological measurement*, 20(1):37–46, 1960.

[84] Mary L. McHugh. Interrater reliability: the kappa statistic. *Biochemia medica: Biochemia medica*, 22(3):276–282, 2012.

[85] John W. Creswell and Dana L. Miller. Analyzing Qualitative Data. *Theory into practice*, 39(25 Jun 2010):124–130, 2000.

[86] Sreyashi Jhumki Basu, Angela Calabrese Barton, and Neil Clairmont. Developing a framework for critical science agency through case study in a conceptual physics context. *Cultural Studies of Science Education*, (May), 2008.

[87] Angela Calabrese Barton and Edna Tan. We be burnin'! agency, identity, and science learning. *Journal of the Learning Sciences*, 19(2):187–229, 2010.

[88] Kelsey Funkhouser, Marcos D. Caballero, Paul W. Irving, and Vashti Sawtelle. What counts in laboratories: Toward a practice-based identity survey. In *Physics Education Research Conference 2018*, PER Conference, Washington, DC, August 1-2 2018.

[89] Robert Beichner, Ruth Chabay, and Bruce Sherwood. Labs for the matter & interactions curriculum. *Am. J Phys.*, 78(5):456–460, 2010.

[90] Edward F. Redish, Jeffery M. Saul, and Richard N. Steinberg. Student expectations in introductory physics. *Am. J Phys.*, 66(3):212–224, 1998.

[91] Benjamin M. Zwickl, Takako Hirokawa, Noah Finkelstein, and H. J. Lewandowski. Epistemology and expectations survey about experimental physics : Development and initial results. *Physical Review Special Topics - Physics Education Research*, 10(1):010120, 2014.