# Transfer Students Redefining Physics Culture: Student Agency and Responses to Traditional Physics Education

By

MARY KATHLEEN CHESSEY

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Approved:

David Webb, Chair

Daniel Cebra

Karen Ann Watson-Gegeo

Committee in Charge

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*To Dr. Moss, who led by example and set me down this path,*

*and*

*To Wendell, who encouraged me and believed in the value of this work*

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# ABSTRACT

## Transfer Students Redefining Physics Culture: Student Agency and Responses to Traditional Physics Education

This dissertation reports on a two-year qualitative study primarily focused on junior transfer physics majors in an undergraduate physics degree program at Sun University. Data were collected using an ethnographic approach and analyzed using a critical theoretical framework. Many physics students held the belief that a career in physics was not intended for people like them, but used characteristics of stubbornness and passion for the subject to defy expectations. Factors such as age, ethnicity, gender, and family background influenced students' behavior in academic physics settings, which revealed a set of implicit cultural expectations for undergraduate physics majors in a large research university. During the period of observation of upper division physics transfer students, study participants adapted to the unfamiliar environment and cultivated an active community focused on inclusion. The discussions and activities within this community highlighted the elements of traditional lecture-based physics education that isolated and discouraged students, especially the teacher-centered format and low average exam grades. At the same time, students made a livable working environment for themselves using strategies of resistance and mutual support. Through the collection and analysis of empirical evidence, physics students' ideas and activities revealed the ways in which formal university physics education promoted subjective and culture-bound practices.

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# Chapter 1

# Introduction

## 1.1 Organization of This Dissertation

This dissertation reports on a qualitative study primarily focused on junior transfer physics majors in an undergraduate physics degree program at Sun University[1] between 2016 and 2018. Chapter 1 provides some background to this study by reviewing the existing literature relevant for physics education research focused on culture in science, technology, engineering, and mathematics (STEM) fields. Chapter 2 describes how this ethnographic study was carried out and the reasons for specific data collection and analysis choices. Chapters 3, 4, and 5 report findings from this study. Chapter 3 describes patterns in behavior and social norms which were revealed through careful, repeated observation and interaction in the setting. Chapter 4 examines the most prominent interface between the setting and the participants: grades. Chapter 5 finally places the focus on the students as active agents in the setting, with the capability of reshaping and defying physics norms as well as embracing some aspects of them. Finally the dissertation wraps up with a conclusion, Chapter 6, which extends the discussion of each of these findings and suggests future work.

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[1] A pseudonym

## 1.2 Motivation

In the United States, the mission of improving numbers of women and people from underrepresented ethnic and racial groups in STEM fields has been met with numerous studies, research opportunities and fellowships to encourage participation, as well as funding for continued exploration of the persistent problem [11]. Physics stands out from other STEM fields as one of the worst for diversity of race and ethnicity. Physics and engineering have the smallest percentages of women graduates among STEM fields, at only twenty percent [2]. Many factors contribute to the disproportionate attrition of women and people of color in physics, but a clear picture of the source of the problem is not yet clearly established among physicists. Many surveys report on the differences in support available to physicists as a function of various components of identity [16], but the inner workings of how it is that some of these social forces influence academic and career trajectories of individuals have yet to be thoroughly described.

## 1.3 Literature Review

Section 1.3 is organized into four subsections. Section 1.3.1 identifies how other scholars have described and delineated physics as a unique scientific discipline. Section 1.3.2 covers some history of science education in the United States, especially how physicists influenced high school physics in public schools. Section 1.3.3 makes a case that cultural choices influence practice and thought in physics despite claims of objectivity. Section 1.3.4 describes how human cultural practices and beliefs interact with and influence students in STEM classes.

### 1.3.1 Physics as a Discipline

Biglan used survey responses from over 200 faculty members distributed across academic areas to classify academic domains along three dimensions discovered through factor analysis: pure or applied, hard or soft, and life system or nonlife system [3] and revealed differences in structure and output in university departments on the basis of these dimensions [4]. Physics was found among pure, hard, nonlife system domains, along with astronomy, chemistry, geology, and math. These areas were characterized by independence of application to practical problems (pure), subscribing largely to a single body of theory or paradigm (hard), and dealing with inanimate objects (nonlife system). For comparison, *applied*, hard, nonlife system domains included engineering fields. Pure, *soft*, nonlife system domains included philosophy and communications. Pure, hard, *life system* domains included microbiology, physiology, and zoology. Differences in beliefs about knowledge, or epistemological beliefs, were found between disciplines by the pure-applied and hard-soft dimensions [21].

## 1.3.2 History of Science Education in the United States

One of the main themes of the history of formal science education in American schools is the prevalence of the use of or opposition to the banking model of education and the role of the banking model of education in maintaining similarity of systems through time. I will provide some description and examples of the banking model, then discuss how it is used to privilege the present dominant ways of knowing and doing science, and lastly a couple of examples of how ideals fail to translate to practice illustrate problems with communication.

### 1.3.2.1 The Banking Model of Education

Describing two ends of a continuum as "educational sects," Dewey characterized one side as perceiving the child as, "simply the immature being who is to be matured," and "It is his to receive, to accept. His part is fulfilled when he is ductile and docile" [10, p. 186]. Dewey described the other sect as prioritizing "self-realization," "not knowledge or information," and active learning involving "organic assimilation starting from within" [10, p. 187]. The "ductile and docile" student representing the first sect fits within Paolo Freire's banking model of education laid out in *Pedagogy of the Oppressed*. Freire explained the "banking concept of education" to be one "in which the scope of action allowed to the students extends only as far as receiving, filing, and storing" the narrated content provided by the teacher [12, p. 72]. Part of the banking model of education includes, "the teacher chooses the program content and the students (who were not consulted) adapt to it," and "the teacher confuses the authority of knowledge with his or her own professional authority" [12, p. 73].

Examples of the banking model of education in action appeared frequently throughout the history of public schools in the United States. Even though notable figures like Dewey, Huxley, Pestalozzi, and Herbart had more active learning ideals for children, somehow we continue to see the banking model in action again and again. For example, Zacharias and Friedman thought of research in physics education as,

> Refining the delivery systems, the exposition, the text presentation, lecture presentation, the films and so forth, to the point that they were so clear and so perfect that any passive student mind would assimilate them simply by having it drop in. That was what research was going to be  delivery  and there was no conception of listening to what the students said when you gave them the opportunity to reflect or talk about something [8, p. 7].

Two further examples of the banking model of education at work are in the founding missions of the American Physical Society (APS) and the American Institute of Physics (AIP). Founded in 1899, APS's stated mission was, "to advance and diffuse the knowledge of physics [2]." Here knowledge in physics may be "advanced" rather than questioned, discussed, reconsidered, reframed or any other more complex interactions. Knowledge in physics may also be "diffused" as if it is fixed, ready to go, and only in need of being understood by more people. The early activities of APS were to hold four scientific meetings per year and to publish the *Physical Review*. These meetings and publications were largely designed by and for scientists, which made way for the later ideas that good physics education could be about scientists "refining the delivery systems" rather than consulting students about appropriate program content. In 1931, AIP was founded with the mission of, "the advancement and diffusion of knowledge of the science of physics and its application to human welfare [1]." Again, even though human welfare is now considered an application of the "knowledge" of physics, the scientists are the experts and everyone else should be the passive recipients of information.

#### 1.3.2.2 Power in the Banking Model

Inherent within the banking model of education is the teacher's or expert's greater power and value than the students or public have. The teacher has knowledge of the right information and the right way of doing things, and the students' success is determined by their ability to understand, accept, and apply this knowledge. When there is a disagreement or misunderstanding between teacher and student, a simple banking model interpretation is that the student has deficiencies and can be helped towards a better way of seeing things. Several examples of this exact thought process by physicists about the public are highlighted here.

The Stanford Linear Accelerator Center (SLAC) has faced off with local residents over safety and aesthetic concerns. An anthropologist who worked at and studied the physicists of SLAC told the story:

> Many neighbors were frightened of radiation or possible explosions (harking back to the association of physics with weapons research). Others were known to be offended by the huge power lines that provide electricity for the lab... The compromise struck was to have the poles designed by a prestigious... architectural firm... and to keep them painted green. The physicists regarded all these concerns as silly, a sign of ignorance, and a confusion of priorities [32, p. 21].

Here the disagreement between physicists and neighbors of SLAC was summed up by the physicists as entirely the fault of the residents for not understanding. The community members' values, concerns, and priorities were not seen as legitimate. Fortunately a compromise was made, likely due to the wealth of the residents who were able to fight for their own interests. In general, "disagreement with the lab's policies is seen as a result of lack of information, which SLAC will supply [32, p. 22]."

Further examples of experts privileging their own understanding above questioning come from Rudolph's book, *Scientists in the Classroom*. Rudolph says, "although the Education Panel... cast the problem as one of mutual understanding... PSSC and PSAC viewed the difficulty... as the public misunderstanding science," and by "understanding" they meant, "appreciation, respect, and even deference [25, p. 134]." The PSSC was the Physical Science Study Committee created in 1956 and the PSAC was the President's Science Advisory Committee established in 1951. The scientists even envied the ability of the totalitarian Soviet government to force the entire society to study and prioritize scientific advancement. In the end, the American scientist's, "models of dissemination were designed for expediency, not for reasoned deliberation of or public participation in determining the fate of education... Perhaps those involved felt that this was simply the price to be paid to gain a foothold for pure science in the classroom [25, p. 175].” In this example we see scientists subverting a slower, more rational process of discussion in favor of quicker power and control over classrooms. In this way, the work of the scientists to influence American classrooms was centered around the idea that the scientists themselves knew better than teachers how best to teach science to children.

In the following section, ways in which two groups fail to understand one another or an ideal is not upheld in practice are discussed.

#### 1.3.2.3 Communication

In *The Struggle for the American Curriculum*, Kliebard states that, “different segments in any society will emphasize different forms of knowledge as most valuable for that society” [17, p. 7], and that seemed to be true between scientists and educators. In the case of science education, there was an agreed upon dissatisfaction with the outcomes of public education, but different groups distilled the problem in different ways and came up with different solutions. Scientists deliberately sidestepped the expertise of educators in the creation of new high school science curriculum, prioritizing the disciplinary organization of material over the educators’ understanding of student development, interest, and motivation [17]. Physical scientists did not learn history or education or social science in their training. According to a 1920 National Education Association report, it was known that lecture is too often assumed to be effective when really teachers should just serve as guides while students solve problems and use their own mental processes to arrive at generalizations [9, p. 75]. This was in 1920, yet Zacharias and Friedman came around decades later and still thought students could passively receive understanding from teachers. Part of the problem seems to stem from failing to see the contributions others can make by privileging one’s own understanding too highly.

One final example illustrates the mismatch between theory and practice. Kliebard describes, “As that metaphor became firmly established, the implicit injunction to think of the mind as if it were a muscle began to lose its ‘as if’ quality, and, to many teachers the mind became quite literally a muscle. To a large extent, the belief that the mind was in fact, or at least like, a muscle provided the backdrop for a regime in school of monotonous drill, harsh discipline, and mindless verbatim recitation" [17, p. 5]. Sutton also described in detail and depth the close connection between language and understanding in science and how this evolves over time [31]. We see how the language used, "the mind is like a muscle," can be re-shaped and reinterpreted to the point that theory and practice no longer match. This danger is always present when trying to get massive adoption of a new technique. Greater cooperation and communication between scientists and educators is needed, unlike the tactics used by the PSSC to publish a new curriculum for high school physics.

#### 1.3.2.4 Summary of History of Science Education in the United States

The banking model of education is frequently applied in classrooms despite the fact that it is ineffective and oppressive. In this model, the teacher or the expert has greater power than the students or public. Failure to understand perspectives different from one's own background leads to mismatch, disagreement, and implementation problems. The Banking Model is a useful description, but the work needed to change this is difficult and often unsupported by appropriate training, salaries, or job descriptions. In the banking model, teachers fail to see the value students bring to the classrooms in their ability to interpret material and apply their perspectives to something new. Scientists fail to see the value of community members' priorities. In both cases, opportunities for cooperation and innovation are lost.

### 1.3.3 Physics as Cultured

In this subsection, I argue that any physics classroom will undoubtedly have cultural norms just as any setting of human interaction, but also that language and forms of knowledge contribute to a cultural component of physics as a discipline. Far from complete objectivity, the knowledge generated and valued by physicists is subject to epistemological beliefs and cultural influences in many ways. Examples of how culture plays a role in physics can be found by comparing the United States to Japan. Government funding models influenced the types of high energy physics detectors built in the two countries [32]. In the United States, a steadier supply of federal funding allowed the development of machines that could be adapted, altered, and replaced over time to serve new and developing purposes. By contrast, in Japan the federal funding was more likely to be a one-time investment, encouraging the creation of high-quality, precise machines that would last many years for similar types of measurements [32]. The detectors influenced the types of research questions that could be pursued in the different laboratories. Another example comparing the United States to Japan concerns national societal values like intergenerational interdependence in Japan and individualism and a free market in the United States. These values factor in to which physics projects get picked up and explored and who gets time on the machines:

> One young physicist at KEK (Japan's National Laboratory for High Energy Physics) spoke of his two years' work in a European lab in a way that I heard echoed many times over. [...] He noted that many students who were very bright and talented were forced to take positions in industry because the professors had taken a personal (not intellectual or political) dislike to them, a dislike that appeared quite arbitrary and unscientific to this young Japanese. He was incredulous at the injustice he perceived. He was startled by the power of the group leaders. New projects were adopted only if the senior physicist chose to become involved. Decisions were made by senior people alone, and younger people were informed of these decisions only if they were on close terms with the decision makers. Since his return to Japan, he has appreciated more fully the freedom, responsibility, and independence granted young physicists there.

In this example, societal values influence the management of large scientific collaborations. Due to the resource-intensive nature of experimental physics, decisions must be made about which research questions to pursue. How these decisions are made, and therefore the direction of the advancement of knowledge in physics and of physics as a discipline, are bound to the human interactions governing activity in the field.

In schools, "physics subject culture" in K12 education is defined and maintained within school systems where teachers' primary objective is to convey truth about nature in the form of clearly expressed, definite knowledge [15]. Physics subject culture also emphasizes knowledge as a collection of facts, is rarely creative, and utilizes strongly structured, teacher-centered, teacher-dominated lessons [15]. Authors describe how curricula, state-wide standards and assessments, principals in schools, and teachers themselves reinforce such a subject culture through vague statement of history and philosophy of science (HPS) learning goals without corresponding implementation or training, textbooks which present history as isolated facts separated from other physics content, and discomfort with the instructional strategies needed to promote students' learning of the nature of science [15]. In this way, students' earliest introductions to physics as a discipline are determined by the teachers, administrators, and governing bodies around their schools. Physics subject culture takes on a very particular form that depends on the people involved rather than on the discipline as it is practiced by physicists.

Within physics, academics carried culture-bound beliefs about people and society. A survey of graduate students, postdocs, and faculty about the importance of raw, innate talent or brilliance for success in their discipline revealed a negative relationship to the percentage of female and of African American PhDs in their discipline [18]. Researchers found also a negative relationship between field-specific ability belief and welcomingness towards women, suggesting that facing stereotype threat, discrimination, and other such obstacles may account for the correlation rather than a true absence of innate ability among women and a true need for such ability. Physicists tend to hold the highest ability beliefs about the importance of innate brilliance for success in the field, second only to mathematicians [18]. Computer science and engineering are the other two STEM fields with relatively high ability beliefs. Among social science and humanities fields, English literature and music composition hold similar ability beliefs to physics, and philosophy holds the highest ability beliefs of all disciplines. On the other end of the scale, molecular biology, neuroscience, and earth science are lowest among STEM fields for ability beliefs, with similar scores among the social sciences and humanities to sociology, anthropology, and archaeology. Education and psychology have the lowest ability beliefs. This study found a link between stereotypes about intelligence in society and the prevalence of a lack of welcomingness in a field of study against segments of society stereotyped as less intelligent.

Numerous studies describe and quantify the significant role language and culture play in teaching, learning, and communicating about physics. Differing cultural norms between representations in physics and in mathematics (for example, equations with parameters) lead to confusion for students when left as a matter of hidden curriculum, and these differences come from typical practices and norms that differ between fields [22]. Science is a language with norms that are not made explicit but have evolved over time, and language in science is used as a method of persuasion rather than only as a simple labeling of factual information [31]. As an example of these kinds of difficulties for students, Brookes and Etkina (2009) examined how the concept of force can be discussed and understood in four distinct ways that have evolved over time, and that students may use language more aligned with historical uses than modern uses [5].

Language and field-specific cultural norms influence practice and thought in physics, however these concepts do not paint a complete picture of educational outcomes in physics. Identity also impacts physics interactions.

### 1.3.4 STEM Culture Interacts with Students

In the previous subsection, I described some ways in which culture plays a role in physics education and in physics practice. In this subsection I go on to describe how these cultural elements of physics and other STEM fields interact with and influence students.

Ong builds a case that (1) images of physicists as white males discourages women and ethnic minorities from considering physics as an option, (2) physics culture discourages participation by nontraditional students, (3) students want to be ordinary in all aspects of their identity, (4) gender and ethnicity are characteristics that can be at odds with ordinariness in physics, and (5) students wish to be seen as community members or non-members and to appear competent [20, p. 596]. Scientists gain power by claiming to be objective. Physics has a culture of no culture [32], when in actuality doing science entails subjectivity, particularistic practices, and context-dependent assertions. Western science founders of the modern university associated masculinity with the qualities of rigorous intellectual inquiry and objectivity. Contemporary practitioners reward white, middle-class, and male-associated physical appearance and mannerisms like aggressiveness and arrogance, and values such as independence and competitiveness [20, p. 598]. The tension between identities leads many women to leave science and engineering. Whiteness is associated with neutrality, and there are social and political benefits for having light skin and passing as white or performing whiteness. White people can speak as individuals but people of color are considered to speak as a representative of their respective groups. White performers get to seem to speak from positions of neutrality and objectivity due to their normal-ness, which aligns with the accomplished scientist [20, p. 599-600]. These aspects of physics culture and the university were found to lead graduate women of color in physics to perform time-demanding and personally costly work on reshaping and re-imagining images of their bodies to fragment pieces of their identity to appear more ordinary in physics.

In addition to cultural images of who looks like they belong in STEM, educational materials designed for some segments of the population may not universally support other groups. An ethnographer followed Romany children through their mathematics classes for a year and visited and observed the children and their families in their Romany communities [30]. The Romany children, coming from strong oral traditions and plenty of numeration practice through helping with families' businesses, had many skills that could be extremely valuable in their low level math classes, but teachers forced all students to speak only in Greek and to use symbolic representation, which was often confusing for Romany students. The schools gave all students the same books and same curriculum, and therefore disadvantaged Romany students, whose incoming background experience was ignored or belittled, by failing to provide an effective transition to symbolic representations in math for Romany students [30]. Giving everyone the same materials (satisfying the Fairness Model of Equity [23]) hurt Romany students (failing the Parity Model of Equity [23]). It is important to emphasize the point that supplying all students with identical resources and support is disadvantageous for the students whose background differs from the designed materials. Having a tailored curriculum to a narrowly defined type of student, even if that type of student makes up the majority in the school, rewards and privileges some students over others for reasons unrelated to interest, motivation, or potential for success.

Math education has traditionally overemphasized some forms of cognitive style (analytic or field-independent) over others (relational or field-independent), which may disadvantage some groups of students on average (specifically African American or Hispanic students) [24, 33]. The analytic learning style is where students sit a long time, concentrate alone on impersonal learning stimuli, and value organized time-allotment schedules [24]. The field-independent learning style uses competitive activities, individualized instruction, and open-ended discovery more than guided lessons towards expected outcomes [33].

Shifting focus back to higher education, *Talking About Leaving: Why Undergraduates Leave the Sciences* by Seymour and Hewitt is a foundational piece of STEM education research. The 400-page work makes use of three years of interview data collected from nearly 500 students across thirteen colleges and universities in the United States between 1990 and 1993. In the study, Seymour and Hewitt discover a set of common reasons for leaving an intended STEM major or common concerns among students who remained in their STEM major through their senior year. A major finding was that students who switched were not academically distinguishable from students who did not switch, and concerns for switchers were echoed by non-switchers [27].

Building off of prior research, authors orient their work around the knowledge that differences in ability levels do not explain the loss of students from STEM fields but that classroom climate and activities have a huge impact on students' decisions to pursue or abandon STEM fields. Some of these factors include curve-grading and aggressive competition among peers, group study and support, and using assessments as a learning tool [27, p. 13].

Among common reasons for leaving a STEM major are an overwhelming volume and pace of material presented with no time allowances for illness or personal emergencies, a lack of coordination among instructors to plan a coherent assignment and assessment strategy, and the apparent requirement of narrow dedication to the STEM major at the expense of a well-rounded liberal education [27]. Further, a narrative of the ability to succeed given sufficient effort is incongruent with students' experiences of classmates achieving rewards and success without having to try hard, and serves to place the blame on students who are not succeeding for lacking effort. Typically, students switching out of a STEM major undergo a long and complicated decision-making process, often starting with a minor setback such as needing to re-take a class, and concluding with a rough shove based on an academic calendar deadline, 'last-straw' incident, or influence of others [27]. It is uncommon for students to switch out of STEM on the basis of 'finding their true calling' elsewhere. Instead, switchers have to submit to an assumption that they have less ability and moral fiber than their non-switching classmates [27]. In many academic settings, students learn to use grades and exam scores as measures of their comprehension and success as a student, so grades become closely tied to students' self-esteem. With curve-grading, exam scores may be very low, largely separated from understanding of the material, and a competitive environment is created which encourages cheating and hurts students' self-esteem [27]. The weed-out culture of many STEM fields developed in an exclusively white and male context, and tests for behavior that used to be encouraged among Anglo-Saxon males. For example, the lack of a personal relationship with the instructor in most STEM classes discouraged some groups of students more than others [27]. Further, groups of students more likely to blame themselves for their struggles and less likely to question authority tended to be more likely to switch out of STEM majors. Feelings of ethnic isolation were also correlated with likelihood of switching. In sum, [27] revealed the complicated and difficult decision-making process of students who switched and didn't switch from STEM majors, identified many varying motivations for entering and leaving STEM, and concluded that simple ability definitely does not account for the disproportionate attrition from STEM of students from genders and races or ethnicities that are underrepresented in STEM.

## 1.4 Theoretical Framework

The two major features of the theoretical framework underlying this study are: (1) that community culture and individual identity interact and are both negotiated through shared practice [35], and (2) that students with backgrounds that are underrepresented in physics have agency and bring many varying forms of capital with them summing to vast community cultural wealth [36].

The goals of critical research are to center the perspectives of the people who are marginalized in the setting instead of describing deficiencies relative to the dominant cultural group, and to challenge the status quo in order to struggle towards greater social equity [36]. Critical race scholars challenge institutionalized, systemic racism [19]. Their work has educated me and influenced this project, but my research does not qualify as critical race work due to a lack of particular focus on racism. By acknowledging the institutionalized forms of bias in the setting, we also acknowledge the need for transformation in order to empower those who are marginalized. In this work I challenged the prominent misconception that groups that are underrepresented in physics relative to the overall population of the United States of America, such as on the basis of gender or race and ethnicity, are in anyway lacking in terms of interest or capability of succeeding in physics. This study is an empirical investigation to explore important research questions based on this theoretical framework.

## 1.5 Statement of Focus

Qualitative work in physics education research is expanding, and due to the context-specific nature of many qualitative studies, my work contributes to the growing knowledge of physics culture. Critical research in physics education is urgently needed. The initial research question motivating this study was, “What can the perspectives of junior year transfer student physics majors reveal about the culture of physics?” Over the course of the study, more specific research questions emerged, and are stated as follows:

1. In what ways do students’ backgrounds and personal experiences interact with formal physics education? More specifically, which components of formal physics education mediate changes to students’ attitudes and behaviors?

2. How do students take up and resist dominant modes of participation in physics?

An ethnographic approach was used to investigate these research questions, as described in the following chapter.

# Chapter 2

# Methodology

## 2.1 Description of the Setting

This study took place at a large, public, PhD-granting, R1 research university in Northern California called Sun University[1]. Locating a social situation (identified by a place, actors, and activities) for participant observation was the first step for developing new knowledge of physics practice [29].

### 2.1.1 Place: Sun University Department of Physics

Within the main campus of Sun University, the physical area inside and around one building, Main Building[2], served as the primary study site. Two nearby academic buildings, Auditorium Lecture Hall and Classroom Lecture Hall, also captured part of the setting. Within Main Building (Main), participants spent much of their time in classrooms 101, 201, and lounges Main Lounge and Undergraduate Lounge (Undergrad Lounge). Main and Auditorium Lecture Hall shared an underground hallway, and were situated next to each other across a 15-meter-wide pathway. Classroom Lecture Hall was adjacent to Auditorium Lecture Hall, diagonal from Main at a distance of about 90 meters.

The Department of Physics (Physics) was housed within Main, including business offices, employee offices and desks, research laboratories, conference rooms, kitchens, bathrooms, utilities spaces, and classrooms. Main was locked at night and on the weekends,

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[1] A pseudonym

[2] All building, classroom, and organization names have been replaced with pseudonyms

and all offices, labs, meeting rooms, and kitchens in Main were locked at all times with keys available to the employees requiring access. The Undergrad Lounge, illustrated in Figure 2.1, remained open by means of a strategically placed rock to keep the door from swinging closed. Nearby Auditorium Lecture Hall and Classroom Lecture Hall contained large classrooms seating more than 80 people at a time and instructional laboratory space.

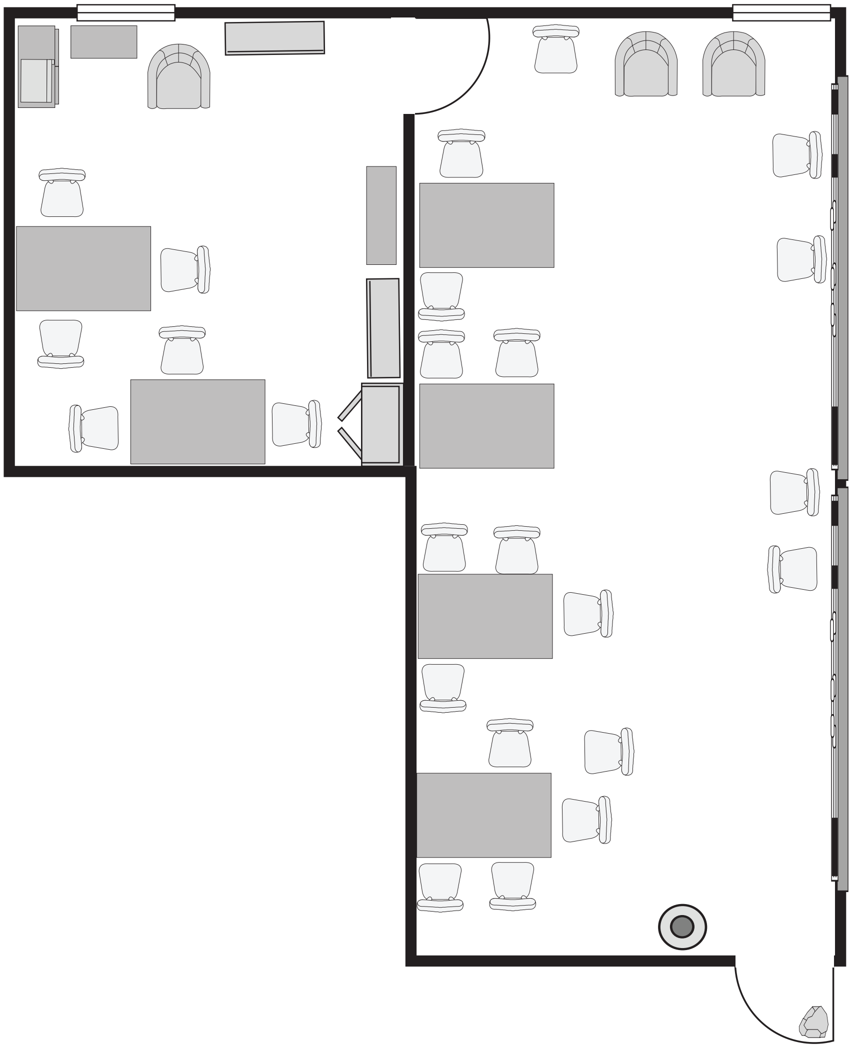

Figure 2.1. Illustration of the Undergraduate Lounge

These three buildings made up a small fraction of Sun University campus, with important administrative and activity hubs located distances between 200 and 1,000 meters from Main (roughly two to twelve minutes moving at three miles per hour). Other features of the campus included dining centers, libraries, administrative buildings, open grassy areas, and many more buildings with classrooms, laboratories, and studios.

Sun University was located in Sun University City on land originally inhabited by the Patwin people. Sun University City grew around a railroad in the 1860s and created a local government in the 1910s. Sun University was formed in the 1950s. Main was built in the 1970s. The area is known for bike-friendliness, agriculture, and plenty of sunshine throughout the year.

### 2.1.2 Actors: Upper Division Physics Majors and Their Instructors

The largest race or ethnicity groups present among over 37,000 undergraduate students at Sun University during the 2016-2017 academic year were Asian or Pacific Islander (35%), white (26%), and Hispanic or Latinx or Chicanx (21%). There was also a large international enrollment (12%). Among 250 undergraduate physics majors (0.65% of Sun University undergraduates), representation of race or ethnicity groups was different: white students made up the largest group (40%), followed by international (25%), and Asian or Pacific Islander (19%). Hispanic or Latinx or Chicanx students made up 13% of physics majors at Sun University during the 2016-2017 academic year. Demographic information about gender was only reported along a male/female binary with no information about other genders among Sun University students. Female students accounted for 59% of undergrads overall but only 27% of physics majors. In summary, Sun University was primarily composed of Asian or Pacific Islander students, white students, and female students while the physics major was primarily composed of white students, international students, and male students.

Two large categories of Sun University physics majors included those who were admitted and attended Sun University starting during their freshman year (freshman admits) and those who first completed lower division and general education coursework elsewhere and then transferred to Sun University at the start of their junior year (junior transfers).

For the junior year cohort observed during this study, approximately half of the class were freshman admits and half were junior admits, which was typical for recent years at the time. Figure 2.2 shows a comparison between groups within freshman admit and junior transfer physics majors at Sun University averaged over the years 2011 to 2017. Among junior transfers, there was a higher percentage of students whose race or ethnicity was underrepresented in STEM than among freshman admits. Race or ethnicity groups identified by Sun University academic research staff as underrepresented in STEM included African American, Black, Hispanic, Latinx, Chicanx, Native American, American Indian, and Alaskan Native groups. There was also a higher percentage of first generation college students among junior transfers than among freshman admits within the physics major. Percentages of female students and of low income students were similar among freshmen admits and junior transfers.

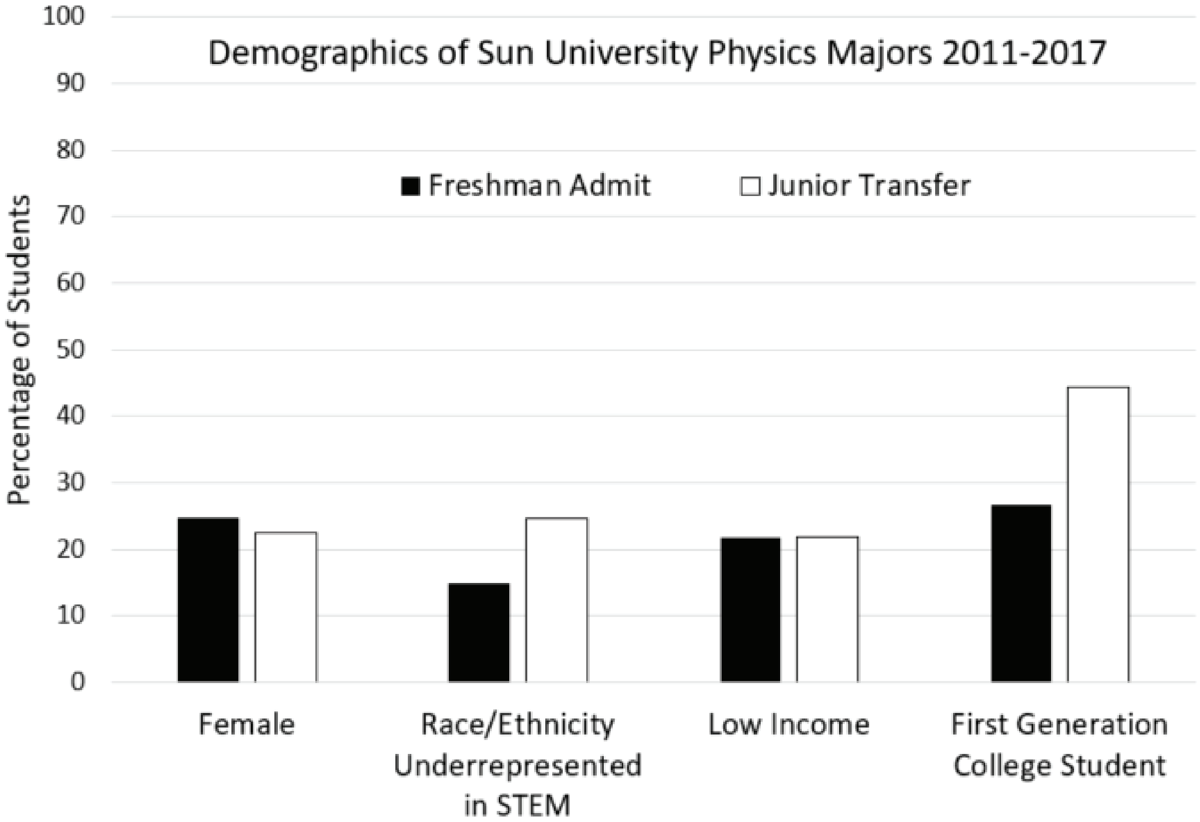

Figure 2.2. Comparison of demographic information between freshman admit and junior transfer physics majors

Participants in this study were recruited by small numbers at a time beginning in October 2016. Participants recruited for the study consisted of junior physics majors, freshman admit and junior transfer both, as well as their "nearest neighbors," or those other members of the Department of Physics community in direct contact with them. These nearest neighbors included faculty members teaching their required courses, graduate student teaching assistants (TAs), and other undergraduate students involved in student organizations alongside the juniors. Overall, 35 people consented to participate in this study, including 27 physics majors (13 freshman admit and 14 junior transfers) and eight instructional staff (six faculty and two graduate students). Gender characteristics were 12 cis-women (34%), one transgender man (3%), and 22 cis-men (63%) participants. Race or ethnicity characteristics were 18 (52%) white, 11 (31%) broadly Asian (including many different national heritages spanning the majority of the world's population), five (14%) Hispanic or Latino, and one (3%) African American participants. Four participants (12%) identified as gay or bisexual or pansexual. Most of the 27 undergraduate participants were between 20 and 22 years of age, with five (19%) undergraduate participants older than 22. A more detailed, descriptive, and personal introduction to the participants is omitted to protect privacy in consideration of the other known or guessable information about the cohort.

### 2.1.3 Activities: Class, Homework, Studying

In the academic setting of Sun University, most activities and the majority of time spent by participants was geared towards academic pursuits. These activities included attending formally scheduled class meetings, usually lecture, going to office hours with a faculty member or TA, working on assigned homework, studying for upcoming exams, or participating in special Open Help Sessions.

Open Help Sessions were sponsored by the department in Main classroom 101 two times per week for two hours each session. Open Help Sessions were planned by a graduate student, who purchased and brought snack food and kept track of attendance and announcements. Graduate students assigned as Teaching Assistants to any upper division physics class were required to attend one hour per week of Open Help Sessions. These sessions were advertised to all physics majors, with particular emphasis on upper division undergraduates. Typically, students were invited to bring their homework to work on or their questions to ask about their homework to the volunteer graduate student tutors.

Another activity common on Sun University campus for participants was carrying out physics research. Research activities took place inside Main in offices or laboratories. Non-academic activities that took place on campus included eating, sitting outside or in the Undergrad Lounge talking in small groups, playing games like chess or other board games, and talking on the phone.

Physics majors at Sun University had two prominent physics-related student organizations they could join: Physics Society and Equity and Inclusion in Physics (EIP)[3]. Activities of student groups took place inside Main Or Auditorium Lecture Hall and included regular group discussion meetings, event planning meetings, officer meetings, and events such as holiday gatherings, performing physics demonstrations for people unaffiliated with Sun University, building fun equipment as a project, and performing. To raise funds for student organizations, undergraduate students hosted events with paid admission or sold merchandise such as T-shirts and buttons. Physics Society meetings were typically attended by between five and 25 people, and EIP meetings were typically attended by between four and 10 people. An event flyer for EIP meetings one academic term appears in Appendix D.

## 2.2 Positionality of the Researcher

In ethnographic research, the researcher is the instrument of measurement. For this reason, the background, experiences, and beliefs of the researcher influence the data they collect and the perspectives with which they come to conclusions. This positionality section attempts to offer a little bit of relevant information about my background and perspectives in physics as they likely influenced the conception and direction of this study.

My undergraduate physics education was completed in a similarly research-intensive physics program, though much smaller in numbers than the department at Sun University.

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[3] Pseudonyms

My desire to pursue physics education research grew out of my unsatisfactory undergraduate experiences in the classroom and of discrimination and bias based on gender. Training for teaching in an active learning classroom and exposure to a wide range of instructional strategies used in my graduate coursework outside of physics showed me that the classroom does not have to be all lecture all the time. Therefore, when I see class time filled completely with lecture during which students sit listening and taking notes rather than engaging with and discussing the material, I feel an opportunity for greater learning is missed.

I assumed that many wonderful students can be interested in physics but that bad classroom experiences can cause stress and push students away from the major. I believe that some stress associated with physics classes is unnecessary, in that it does not cause students to grow in desirable ways such as by skill-building or learning something inherent about the discipline, and that the unnecessary stress comes from poor teaching and classes structured in ways representative of history rather than what's best for learning physics. For these reasons, I often questioned the purpose and expected outcomes of classroom practices, assignments, and assessments.

As an active physics graduate student in the department at the time of the study, I was a highly involved member of the community within Main Building. I assumed that my three years in the department prior to the start of the study and my status as a graduate student granted me a position of authority that led me to take a welcoming and friendly stance towards participants, as if I was able to invite them into my community and offer guidance from my successful experiences in physics.

My positionality changed over time after the start of the study. As the undergraduate participants and I grew more comfortable and familiar with each other, the frequency and quality of informal interactions in Main and on campus increased. I became a resource and contact for my participants in the department, offering information about funding for snacks for meetings, department structure, resources for graduate students that might make sense to pursue for undergrads, information about a small grant opportunity, and some academic support at the Open Help Sessions. By the end of the study, my position relative to the participants active in the equity and inclusion group might best be described as an ally in the department.

## 2.3 Data Collection: Critical Ethnography

Criteria for a good ethnography of schooling include studying events in context, allowing hypotheses and questions to emerge after the start of data collection, carrying out prolonged and repetitive observation, and disturbing as little as possible of the process of interaction and communication [28].

The study site was selected according to five guidelines: simplicity, accessibility, unobtrusiveness, permissibleness, and frequently recurring activities [29]. The way each of these guidelines is satisfied in this study is described here. Actors in physics social situations interact in a great variety of settings that influence their behavior, which may lead to the idea that researchers must observe and study physics actors in all these different locations and settings in order to describe physics culture. However, for the sake of simplicity, a single academic building, Main Building on Sun University campus, served as the central location for initial observation, which eventually extended to include two additional nearby buildings where study participants gathered. Accessibility to Main was ensured by my status as an active graduate student with a key that unlocked the building's exterior doors, most classrooms, and my office located just around the corner from the Undergrad Lounge. Some settings, such as class lectures and informal homework sessions in the Undergrad Lounge, called attention to my presence as someone not enrolled in or assigned the same work as the study participants. In these cases, a peripheral location within the room and especially out of the way of chalkboards was selected for observation to reduce obtrusiveness. In other settings, such as Open Help Sessions between graduate and undergraduate students and in regularly scheduled group meetings, unobtrusiveness was granted by the public and open invitation of the meetings and their location within Main where I was commonly found for reasons unrelated to the study. During interviews and Open Help Sessions, I played a more active role by engaging participants in discussion or working together on an assigned problem set. Permissibleness of the study setting was improved as an active student at the university, so limited-entry social situations (for example, club meetings open to all students but not advertised to the general public) were available to me. For observation of class lectures, permission was first requested from and granted by the class instructor either through email or in person. In two settings, office hours and in the back room of the Undergrad Lounge, permission to observe was explicitly sought from all participants at the beginning of each observation before I took a place at the edge of the space. Finally, by observing participants while academic terms were in-session in locations where classes, studying, and homework were often carried out, many frequently recurring activities were captured in the data, such as asking and answering questions, solving physics problem sets, expressing uncertainty, and sharing information.

Data were collected throughout the 2016-2017 academic year between October 2016 and June 2017 as well as during the first academic term of the 2017-2018 academic year between September and December 2017. The timeline for data collection overlapped time spent indexing, transcribing, and analyzing data to allow for an iterative approach to data collection and analysis. This *theoretical sampling* strategy reduced the overall volume of data in favor of depth as I refocused new data collection on core explanatory themes as they emerged from rounds of data analysis [13]. The types of data collected included field notes created during observations and expanded within 24 hours of the time of the observation, audio recordings gathered during observations, interviews, academic support interactions, and photographs of settings, flyers, and participants' written work. Ethnographic field notes were recorded in a two-column format, with low-inference vocabulary used ("they shouted") in the left column and comments with speculation about meaning, thinking, and feeling ("they were angry") in the right column [6]. Audio recordings were captured using a combination of microphones in my laptop, smartphone, and dedicated devices (Sony ICD-UX533BLK Digital Voice Recorder) that were placed on desks or near chalkboards during observation. Additional data were collected from instructors of the six major classes typically taken by junior physics majors at Sun University. This additional data included course syllabuses, problem set assignments, quizzes and exams, and grade information. De-identified grade information was collected for all enrolled students, including individual homework, quiz, and exam scores as well as overall course grade assigned, following the close of classes for all six major classes. These differing slices of data permitted a multi-faceted investigation [13].

During fall term of the cohort's junior year between October 24 and December 9, 2016, I observed seven class meetings, six Open Help Sessions, five informal group work gatherings, one EIC student organization meeting, and conducted nine interviews with individuals or small groups for a total of 22.2 hours of data collection. The following quarter, I participated in individual tutoring for five one-hour sessions and observed four lectures and one problem session for a total of 11.8 hours of data collection between January 26 and March 20, 2017. In the spring, I observed 25 lectures, two informal group work gatherings, six Open Help Sessions, two office hours and a faculty problem session, and conducted twelve interviews for a total of 44.4 hours of data collection between April 3 and June 16, 2017. Finally, in the fall of the cohort's senior year, I attended nine student organization meetings, five department events (four of which were organized by student groups), and conducted 18 interviews for a total of 36.4 hours of data collection between September 29 and December 20, 2017. Across these four academic terms, I collected 114.8 hours of data in the form of field notes and audio recordings. Typical observation sessions ranged in duration from ten minutes to over two hours and were characterized by a single location (a classroom, lecture hall, computer lab, office, or lounge) and core group of participants without a large fraction of variation during the time of the observation (as few as one person for an interview or as many as about 80 people during lecture). Interviews were either one half hour or one hour in duration. Summaries of data collection efforts can be found in Table 2.1 and Figure 2.3.

Interviews were deliberately completely open-ended during the first round in December 2016 to reduce the influence of my preconceived ideas over what the participants shared [28]. As categories emerged from the data, more specific questions for some participants, especially questions pertaining to past events involving that participant, were raised in interviews. This strategy matched the theoretical sampling approach to data collection [13]. Each interview began with an invitation for the participant to share or ask anything

| Type of Data Collection | Date Range | Number of Participants | Duration (in hours) | Data Format |
|---|---|---|---|---|
| Interview | Dec '16,<br>Jun & Dec '17 | 20 | 30 | Audio Recordings |
| Observe Lecture | Oct '16-May '17 | 29 | 37.2 | Field Notes & Audio Recordings |
| Observe Office Hours | Feb-May '17 | 13 | 3.5 | Field Notes & Audio Recordings |
| Participate in Help Sessions | Oct '16-May '17 | 22 | 21.2 | Audio Recordings |
| Observe Outside of Class | Nov '16-Dec '17 | 21 | 21.1 | Field Notes & Audio Recordings |
| Grades | Jan-Jun '17 | N/A | N/A | Numeric & Categorical |
| Total: | 15 months | 35 participants | 115 hours | |

Table 2.1. Summary of collected data

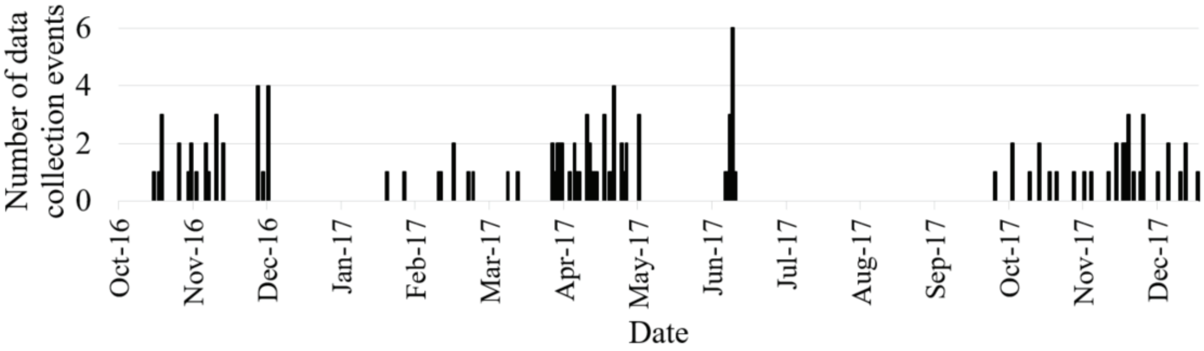

Figure 2.3. Distribution of data collection events over time

they wanted. Questions specific to the individual participant followed. During interviews in spring and fall 2017, some emergent themes were explored such as activities, skills, and hobbies outside of physics, and style of clothing preferred. During spring 2017, identity questions were asked across the board but left open to allow participants to report the aspects of their identity most important to their experience. During fall 2017, interviews were focused on academic and family background before attending Sun University.

## 2.4 Data Analysis

Ethnographic data were analyzed using the constant comparative method [13] described in Section 2.4.1. Selections of audio recorded speech were further investigated using critical discourse analysis [34, 7] described in Section 2.4.2.

### 2.4.1 Constant Comparative Method

One of the greatest strengths of taking an open-ended approach to analysis of ethnographic data is the ability to discover patterns or themes of social interaction in the setting without imposing strictly defined limits on what can be examined based on existing theory. The four stages of the constant comparative method of qualitative analysis were followed: (1) compare events in data to other events fitting within the same category or theme, (2) integrate across events to determine properties of the category, (3) determine the limits of the theory and reduce the number of categories, and (4) summarize the results and write the theory [13].

As a first step to data analysis, the rapidly growing quantities of written field notes and recorded audio needed to be managed. During the most active periods of data collection, I created daily or weekly memos to reflect on the most notable recent events. When field notes and audio recordings were collected simultaneously, such as during lecture observations, the handwritten field notes served as a type of index for the contents of the recording. When audio recordings were collected without written field notes, such as during interviews, then the audio was listened to separately, with summarizing notes about the content written for small chunks of time ranging from thirty seconds to a few minutes. These notes, summaries, and memos were later used for quick reference when reviewing the contents of the collected data for relevance to the emerging categories or themes.

During the first year of iterative data collection and analysis, initial coding of field notes for themes was carried out by hand using colorful stickers to point out examples of emergent patterns. Early on, some of the themes coded in the data included participants' distinctions between disciplines, especially physics and math, routines of question asking and answering during a lecture, and decision-making strategies while problem-solving. In October 2017, funds available to my research group were used to purchase a student license for NVivo 11 Pro, qualitative analysis software. With an active software license, I transferred the entire project into NVivo 11 Pro, including audio files, scanned copies of handwritten notes, text files with indexing of recordings and existing transcripts. I also re-created my colorful sticky note coding structure within the software by utilizing NVivo "nodes" to represent themes from the data. Once the project was completely imported, I continued indexing, transcribing, and writing memos using the appropriate tools within the software. I also continued coding the data using the drag and drop method to mark selections of text or portions of images with the appropriate node. The constant comparative method of data analysis was facilitated by the convenient viewing options within the software to see all instances of the data matching of node or theme of interest.

Field notes were not indexed, but were coded directly. Audio recordings were indexed for content and information such as who were the people present, who was speaking, and what they said especially as related to their identity, position of people in the community, advice to others, questions asked and answered, handling formal class requirements, and other common topics. From indexed recordings, segments to transcribe in closer detail were identified by the theoretical relevance of the content to the developing categories. Transcriptions were coded instead of indexed recordings when available. This strategy allowed for more detailed examples from the data to delimit categories than indexed recordings alone.

As the amount of coded data expanded, initial themes were refined. For example, the theme of distinguishing physics and math as separate disciplines (Once you have set up the problem, then the physics is done and it's just algebra from here) was further developed to include examples where mathematics and physics were united to discuss a concept (Mathematical solutions to the differential equation *are* descriptions of states of the physical system). Finally, themes with many examples from the data were reviewed and described, and can be found in Appendix A.

### 2.4.2 Critical Discourse Analysis

A noteworthy companion to the analysis of data that was collected using an ethnographic approach, critical discourse analysis offers a framework for interpreting multiple meanings of speech and extrapolating information by considering context [7]. Societal power relations also influence discourse, making critical discourse analysis a useful tool for studying power through interactions in the data [34]. To carry out critical discourse analysis on samples of data from this project, I first transcribed sections of audio recordings that were identified as theoretically relevant to emergent themes. The first pass of transcription captured only the words that were said and who the speakers were. On subsequent passes, other features of speech were marked in the transcripts, such as pauses, pacing, volume, and tone. Transcription conventions were adapted from [14] and [26], Appendix 2, From DuBois (1991). See Appendix B for a description of transcription conventions used. Transcribed data were then explored and coded in a manner similarly to how field notes and indexed audio recordings were analyzed as described in Section 2.4.1. Aside from coding transcripts directly, researchers listened to original audio recordings, especially interviews, and discussed patterns observed within and across interviews with participants over time. These discussions informed and influenced the direction of the refinement and development of emergent themes by allowing me to discuss a perspective other than my own to explain speech and behavior recorded in the data.

### 2.4.3 Moving from Themes to Findings

The final stage of the constant comparative method of data analysis involved organizing the many themes into a smaller number of groups in an attempt to improve the understanding of meaning and participation in the social setting. By reviewing and reflecting on the data collection and analysis process and the entire body of data, research questions were settled around the prominent themes of characterizing physicists by a set of common attributes and discovering or creating alternative ways of being a physicist. The result was the development of three major findings, documented in Chapters 3, 4, and 5.

Chapter 3 describes patterns in behavior and social norms in the setting and imagined [35] by participants about similar physics-oriented settings. Chapter 4 examines the most prominent interface between the setting and the participants: grades. Chapter 5 finally places the focus on the students as active agents in the setting, with the capability of reshaping and defying physics norms as well as embracing some aspects of them.

# Chapter 3

# Finding: Description of the Physics Bachelor's Degree Program at Sun University

The research questions are:

1. In what ways do students' backgrounds and personal experiences interact with formal physics education? More specifically, which components of formal physics education mediate changes to students' attitudes and behaviors?
2. How do students take up and resist dominant modes of participation in physics?

This chapter addresses part the first research question by identifying what is "formal physics education" in this setting and what are its components. In the next two findings chapters, we will explore how some of these components impact students and some of the strategies students have for resisting the incompatible or undesirable components. This chapter identifies a narrow range of approaches to teaching physics (Section 3.1), a teacher-centered strategy in many ways (Section 3.2), an emphasis on independent rather than personally guided learning (Section 3.3), the influence of stereotypes of physicists as geniuses (Section 3.4), and the lean towards intellectual curiosity as the primary reason for pursuing physics (Section 3.5).

## 3.1 Narrow Set of Instructional Strategies

An analysis of course syllabuses for the six required junior physics major classes (Analytical Mechanics 1 and 2, Electricity and Magnetism 1 and 2, Mathematical Methods in Physics, and Introduction to Quantum Mechanics) revealed a slim set of approaches to instruction and assessment. Each of the six classes met for three hours per week in a lecture format. On top of that, one or two office hours or problem sessions were scheduled with the faculty instructor and with one or more graduate student TAs or graders for the class. While lectures appeared on the university schedule so that enrolled students did not have conflicts with any other classes on their schedule, the office hours and problem sessions were scheduled informally. Consequently, the ability to attend office hours and problem sessions was not ensured for all enrolled students and time conflicts existed for some fraction of the class. Office hours and problem sessions were similar to each other. In either case, a one or two-hour block of time was scheduled for a room in Main where students could voluntarily go and expect to find the instructor available to them. Often the discussion at these meetings was focused on completing assigned homework problems.

Aside from similar types of meeting formats, assignments across the six courses were of similar kinds. Typically a “problem set” consisting of three to eight physics problems was assigned for students to complete outside of class within a week or two to be turned in individually for grading. Problem sets usually involved problems from the textbook for the class, but sometimes were written by the faculty instructor. Once completed and submitted, problem sets were turned over to a graduate student grader, who would grade them and get them back to the faculty instructor to return to students within a week or two. Problem sets were usually graded “for correctness,” meaning that students’ submitted solutions needed to match an expected solution to the problem based on concepts and techniques covered in class lectures and in the textbook. Problem solutions usually involved many “lines of work,” or gradual steps manipulating equations and relationships using arithmetic, algebra, calculus, or known relationships like laws of physics. Students’ solutions, therefore, could vary and differ from one another throughout these lines of work, but often a final numerical answer or expected relationship would be the desired result, which ought to be the same for everyone. Full credit on problem sets was usually reserved for complete work that was also correct.

The primary mode of assessment was in-class, timed, written, closed-book, individual exams. On average across these six classes, this type of exam accounted for about two-thirds of the final course grade. Each class had one or two midterm exams scheduled during a lecture meeting during the academic term and a final exam scheduled at a special meeting time after the last week of class. These exams would usually have about four problems to solve, similar in format to problems assigned for homework but in some ways less complicated to allow for solving more quickly and with fewer resources than on homework. One class, Quantum Mechanics, implemented near-weekly quizzes in addition to the midterm and final. The quizzes were usually made of one or two very simple questions basically asking students to demonstrate or apply a technique from class to a straightforward and familiar situation. Another class, Analytical Mechanics 2, also implemented written participation grades. Sometimes during lecture, the faculty instructor would have students work out a short problem or copy down a derivation to demonstrate that they were in attendance and paying attention, and then turn those in for credit.

In sum, course grades across all six required junior year physics major classes were calculated using exams, problem sets, quizzes, and written participation grades. I am struck by how all of these formats of assessment and assignment were written, individual, and calculation-heavy (rather than concept or explanation heavy). In contrast, however, outside of these six core required physics major classes, some classes involved a laboratory component, offering distinct modes of instruction and assessment from the six courses analyzed. Laboratory classes involved an additional meeting component where students could work at computers in a computer lab on programming projects or in groups around experimental equipment. Even in these lab courses, however, laboratory reports and programming assignments were still submitted in paper format by all individuals.

## 3.2 Teacher-Centered

Class time was extremely teacher-centered in terms of who spoke, who decided the topic, how the classroom was laid out, and which knowledge and skills were valuable.

### 3.2.1 Classroom Layout

Classrooms were designed and built for large groups of students to pay attention to a single instructor at the front of the room without peer-to-peer collaboration, evidenced by fixed, forward-facing seating for 80 or more audience-members at a time. Figure 3.1 shows such a classroom layout while the instructor lectures from the front of the room with wide-open floor space, four chalkboards that slide to reveal more chalkboard space behind, and a table to place class materials, lecture notes, or a binder. The instructor also controls a retractable screen, audio and visual hookup for projecting, and lighting in the room from the front area. Two doors on either side of the front area have signs indicating that only staff may use them, which lead to back hallways connecting to the Main Building. Students enter from the back of the room from outside of the building. The students in Figure 3.1 sit in their seats listening to the instructor almost completely without ever speaking while taking notes on their small, folding desks. Some students write in notebooks, others have out a tablet or smartphone, and some sit with their desks away and nothing in their hands or lap. Note-taking typically occurs on blank notebook pages or electronic documents, forming a clear analogy to the banking model of education, whereby instructors impart their valuable knowledge on passive, receptive students who lack this knowledge [12]. In Figure 3.1, we see a large spread of papers on the instructor's table. These were homework assignments that had been previously turned in, graded, and now were being passed back to the students. The instructor spread these out on the table at the beginning of class time for students to individually take back. While this process invited students to briefly share in the instructor's space at the front of the room, it also eliminated an opportunity for the instructor to read and say students' names and to see students' faces connected to these names and scores on the assignment. Figure 3.2 shows another room where many required major class meetings took place. Again, the instructor has a clearly distinguished area at the front of the room, large tables for materials, papers, notes, and a beverage, chalkboards across the front wall, and students sit in fixed, forward-facing seating. In this case, the seats swing and pivot, but are still attached to the ground. In this case rows of tables are available for students, providing greater working space than the small folding desks, but each student still has less working space than the instructor has at the front of the room. All doors in this room are equally accessible to staff and students. On the students' tables, some students have placed bags, textbooks, and beverages in addition to notebooks, smartphones, or tablets.

Figure 3.1. Photo taken during class in Auditorium Lecture Hall, May 2017

### 3.2.2 Control Over What Was Said

In addition to lecture, instructors and teaching assistants hold office hours or problem sessions once or twice each week for one hour at a time. The format of these meetings fell into two main categories: (1) lecture-like and (2) recitation-like. Professors Almond and

[redacted]

Figure 3.2. Photo taken during class in Classroom Lecture Hall, April 2017

Pistachio took the lecture-like approach and typically would stand near a chalkboard, take students' questions about problem sets or practice exams, and offer guidance, hints, clues, or help about solving the problems. Professor Avocado and graduate student teaching assistants, including Eugene, took the recitation-like approach and would prompt students to take the chalk or dry erase marker to the board to demonstrate their progress in problem-solving for the group as a starting point for discussion.

Figure 3.3 shows how the lecture-like style used by Professors Almond and Pistachio resembles typical lecture format with students sitting facing forward, listening, and note-taking while the instructor stands and explains at a chalkboard. There were important differences between lecture-like office hours or problem sessions and actual lecture, however. The percentage of attendees speaking during office hours to ask or answer questions was much higher than during lecture. Importantly, office hours started with the instruc-

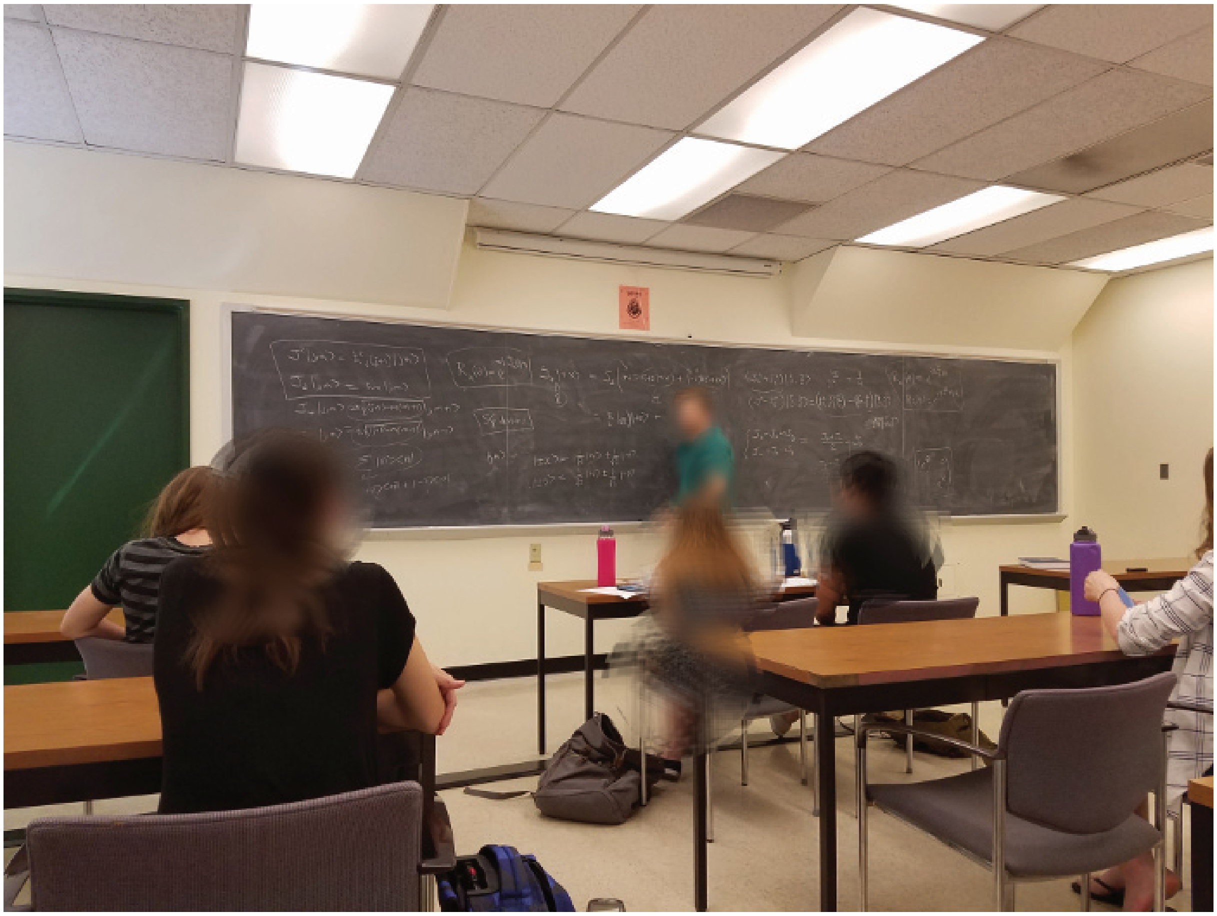

Figure 3.3. Photo taken during Professor Pistachio's office hours, May 2017

tor waiting for questions from students. In lecture, the instructor speaks for most of the time and only occasionally pauses to accept students' questions. In this format of meeting, participation remained largely teacher-centered and banking model, but the element of teacher control over the precise content and examples discussed was turned over to students.

Figure 3.4 shows an example of the recitation-like problem session format utilized by Professor Avocado and graduate student teaching assistants, in this case, Eugene. A particularly notable contrast in this setting than in lecture or lecture-like office hours is the position of the 'instructor,' who in this case is seated evenly with the students all oriented towards the side of the room rather than towards the front. This group has resisted the teacher-centered design of the classroom by turning chairs to face the side white board instead of the front chalkboard. Penguin and Jade are seen to the left sharing a working space for ease of collaboration. The writing on the board was contributed not only by Eugene but also by students prompted by Eugene. I named this style of problem session recitation-like rather than 'discussion' or 'collaboration' because participation was still controlled by a single instructor, who invited students to demonstrate what they had already worked out or to answer very specific questions that aligned with the instructor's intended problem-solving approach. For example, Mayzee described standing at the board in Professor Avocado's office hours being asked to draw a force diagram. Mayzee drew the diagram missing one of the forces needed for solving the problem, and the instructor asked what was missing and waited while Mayzee repeated that she did not know. In this example, Professor Avocado controlled the dialogue even though Mayzee was participating by writing on the board in front of the group. In the recitation-like sessions, active learning techniques were utilized by having students write on the board and answer questions, unlike the passive banking model approaches used during class and lecture-like sessions, but in all cases the interactions were teacher-centered.

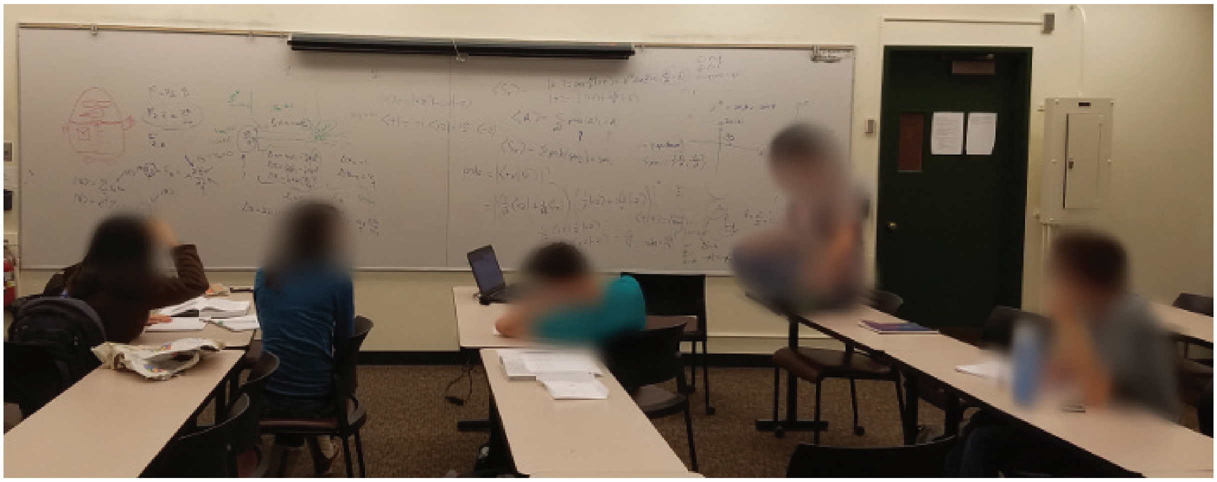

Figure 3.4. Photo taken during a problem session with Eugene, April 2017

Not only did faculty instructors and graduate student teaching assistants impose a banking model approach to office hours and problem sessions; students expected this format, too. Jake found problem sessions where the professor goes through "everything you need to know for the homework" as extremely useful when he was not sure how to get a problem started or if the answers he was finding were not making sense[1]. Office hours with a graduate student TA were frustrating for Jake when the TA "wouldn't prepare" and worked as a collaborator alongside the students. The teacher-centered focus in problem sessions therefore was not simply an overbearing instructor leading unwilling students along; many students like Jake expected and appreciated such a structure where they received information from the instructor.

### 3.2.3 Decisions About What Was Important

Instructors in the Department of Physics at Sun University had a tremendous amount of freedom over how to run their courses, such as by writing the syllabus, choosing the problem sets and exams, and deciding how to calculate students' final grades in the class. For example, during a continuum mechanics lecture, Prof. Rice informed the students of the class that, "Later [during the term] we'll throw in superfluids just cuz it's fun[2]." In this example, covering superfluids was optional rather than a required topic according to the university course description. Prof. Rice decided to include the topic in the class because of assumed popular interest in these materials and the application of the theory from the class to something observable in a laboratory. The bare-bones course description left plenty of open space for instructors to be flexible and adaptive in this way:

> The continuum hypothesis and limitations. Tensor methods develop stress-strain relations for linear isotropic solids/fluids and field equations to study wave propagation in solids/fluids, heat flow, potential flow and ocean waves.

As another example, instructors made decisions in their classes on-the-fly which impacted students but did not rely on student perspectives to inform these decisions. During the students' second academic term at Sun University, Mr. Pink attended a problem session of Prof. Almond and asked permission to evaluate an integral by looking it up in an integration table rather than calculating it by hand. Prof. Almond replied, "I'm teaching physics not mathematics so you can do whatever you like[3]." In another class less than one week later, Prof. Wheat announced during lecture that on the recently submitted

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[1] Interview June 14, 2017

[2] Field notes during lecture April 4, 2017

[3] Field notes during problem session February 22, 2017

homework, some students had used software to work through the algebra to solve problems. Prof. Wheat said, “But um boy you get a awful answer and just because this one is a real pain, to do, some people have resorted to Mathematica, I guess I would say please don’t/ ((laughter)) huh you should do the algebra.[4].” In this striking example, two faculty members made decisions about acceptable student activity while completing problem sets which were exactly contradictory. Further, based on the way that Prof. Wheat delivered his decision, it was made with more uncertainty than conviction. Prof. Wheat used “I guess I would say” rather than a more direct and certain command, raised his pitch on the word “don’t” in a question-like tone, and laughed before concluding “you should do the algebra.” Possibly Prof. Almond’s decision to allow the use of integration tables and Prof. Wheat’s recommendation to “do the algebra” are firm and long-standing beliefs held by the two instructors rather than decisions made on-the-fly. In either case, it is not necessarily clear to the students the reasons for these decisions or that the two instructors have ever discussed this matter together to create a cohesive educational program. Instructor variation can causes courses to be different from one implementation to another, firmly tying education in physics to a human component.

In another similar example, Prof. Wheat chose a sign convention for a space-time metric setting a positive value for time and negative values for each of the three spatial dimensions[5]:

$$ds^2 = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & -1 \end{pmatrix} \begin{pmatrix} c^2dt^2 \\ dx^2 \\ dy^2 \\ dz^2 \end{pmatrix} = -dx_1^2 - dx_2^2 - dx_3^2 + c^2dt^2 \tag{3.1}$$

Equation 3.1 provides the definition for an invariant interval, $ds^2$, which is special because the value of the interval is the same no matter which frame of reference you use. By this sign convention, two events that happen at the same time but separated by space will have a negative value for this interval. Once Prof. Wheat wrote this on the board during

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[4] Transcribed audio from lecture February 28, 2017

[5] Field notes during lecture March 2, 2017

lecture, a student in the class, Mark, commented, “That’s not what [another professor] is teaching us.” The convention used in Mark’s other class was:

$$ds^2 = \begin{pmatrix} -1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} c^2dt^2 \\ dx^2 \\ dy^2 \\ dz^2 \end{pmatrix} = dx_1^2 + dx_2^2 + dx_3^2 - c^2dt^2 \qquad (3.2)$$

By the sign convention in Equation 3.2, the same two events from before that are separated in space but happen at the same time will instead have a positive value for this invariant interval. Both sign conventions are valid when used consistently but cannot be mixed with each other. Another student, John Snow, raised his hand to ask whether students may choose which sign convention to use in their own problem-solving. Prof. Wheat replied that students should stick to the convention used in the assigned textbook for the class (Eq. 3.1), which set time as positive as stated during the lecture and opposite from what was taught in another class, “at least for the TA’s sake,” who I assume would be grading the problem sets and would likely benefit from consistency in convention choice across all students. In my view, the benefit to the grader, which would have been to have one correct solution instead of two possible solutions that differ from each other only by a sign only if all students adhered to the textbook convention, was outweighed by a possible negative impact of seeing how something that seems it should be an arbitrary choice left to the problem solver actually also ends up determined by the instructor and can be preferred or not. The message that was broadcast from this example in class was that physics problem-solving may be riddled with many choices, some of which are completely arbitrary, but that the instructor still has a preferred set of choices which could possibly impact grading of student work in the class.

Section 3.2 shows how decisions are made by faculty and are not necessarily grounded in the diverse experiences of the student body. Section 3.3 explores in further depth one element of the teacher-centered physics bachelor’s degree program at Sun University: the emphasis on independent or unguided student learning.

## 3.3 Emphasis on Independent Learning

Students spent a large fraction of their time outside of lecture working on physics homework or studying for physics exams. Many participants took a strategy for completing problem sets by starting completely on their own before consulting with anyone else. For example, before attending office hours or problem sessions, Jake would first work independently using the textbook and class notes as resources[6]. Checking with friends and searching online for help were additional tactics before resorting to instructors or TAs. Jaya also reported first tackling assignments on her own, working independently for a few days, and then coming together with a classmate who was a friend to compare work before the assignment was due[7]. Most participants reported or were observed to work with classmates outside of class at some point. Even when students like Jake and Jaya discussed with their classmates about coursework, these interactions took place outside of class without instructor or TA guidance or supervision. In this section, the emphasis on independent learning sometimes means learning while alone but also means learning outside of class without instructors.

The next three subsections provide some reasons for the emphasis on independent learning: (1) students and teachers valued individual students' understanding of the material, (2) time in class was extremely limited, and (3) time with instructors typically marched forward according to the input from the most vocal students, leaving others to catch-up or explore on their own.

### 3.3.1 Value Placed on Individual Understanding

The first reason I found for the importance of unguided student work was that students and instructors valued individual students' understanding of the course material. For example, student Richard Feynman avoided office hours where the instructor provided "too much" assistance setting problems up to solve because he felt the purpose of the homework was to learn how to set the problems up on his own[8]. Jade preferred to attend office hours after she had already mostly completed the homework because the time spent

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[6] Interview June 14, 2017
[7] Interview June 15, 2017
[8] Interview June 14, 2017

was more useful than when she had not yet attempted the problems and just took notes like during lecture[9]. Penguin and Jaya were both observed separately to prefer working alone at times during unstructured tutoring hours to review their notes and their work just to make sure they understood[10]. While working with a partner on homework in the Undergrad Lounge, Mark wrote his own notes on paper even though his classmate was writing everything on the chalkboard because he wanted to make sure that he would be able to get it for himself[11].

Faculty also indicated the importance of working outside of class without instructor guidance for the purpose of improving students' understanding and skill in physics. Prof. Tomato advised students, "If you see things in homework canceling, see if you can get it a shorter way, then you'll gain insight and be able to answer questions faster on the GRE[12]." While discussing a problem in classical mechanics from the center of mass reference frame, Prof. Avocado stated, "There is work involved to go between [the two frames of reference] but the advantage [of the center of mass reference frame] is simplicity. I encourage all of you to work in both frames and practice going between them[13]." Prof. Pistachio derived a result in quantum mechanics but left some arithmetic steps out of his work on the board and said, "I'll leave this as an exercise. You should check it at home to make sure you understand. You should really work this out; you really need to understand. It comes up time and time again in quantum mechanics[14]." In these three examples, faculty told students during lecture that they should practice and work outside of lecture with the goal of improving students' understanding and comfort with the material.

In these examples, instructors tended to encourage students to go over material outside of class, but not necessarily alone as opposed to with classmates. The value seemed to be that each individual student should understand the material on their own, but may reach that understanding by collaborating with their peers. This value aligned with the forms of assignments and assessments in all classes, which required each individual student to

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[9] Interview June 16, 2017
[10] Observations October 27, 2016 and October 21, 2017
[11] Observation April 3, 2017
[12] Field notes during lecture October 26, 2016
[13] Field notes during lecture November 8, 2016
[14] Field notes during lecture April 7, 2017

submit their own personal written work, whether they had collaborated with classmates or not. Even in the laboratory class where students worked through experiments in groups, the instructor still required all group members to submit their own lab reports. Students themselves were often the ones to take the advice a step further and push themselves to review and ensure their own personal understanding alone, sometimes in preparation for exams.

### 3.3.2 Limited Time In Class

Another major reason for the emphasis on students spending time outside of class working without instructor guidance was that time in class was extremely limited so items that were not prioritized in class but still important were left to students to address on their own. In this subsection, all of the examples came from lecture observations and fell into two main categories: the material was left out either because (1) students should be able to do it on their own or (2) students should already know it.

#### 3.3.2.1 Expectation That Students Did Not Need Further Guidance

Some examples of material that instructors left out of lecture for students to do on their own were because the instructor believed that students should be able to carry out the work independently using resources other than the instructor.

While working at the board during lecture on October 27, 2016, Prof. Walnut said, “Now I won’t do the last eigenmode. I’ll just tell you the answer. It takes a little bit of algebra. You get this funny answer.” In this example, Prof. Walnut was working through a coupled oscillator problem (three masses in a row attached by two springs), which had three solutions. He worked out the first two solutions line by line before jumping to the third solution without working through the steps. Because the steps that were skipped in calculating the last eigenmode had already been carried out on the previous two eigenmodes, Prof. Walnut decided to skip them with the understanding that the students would be able to do those steps on their own. Rather than practice the process of calculating eigenmodes again, Prof. Walnut opted to write the answer in order to forward discussion about the conceptual understanding or the meaning of these values in this problem.

Another example comes from lecture February 22, 2017. Prof. Almond said, "I will not do the math. You can do it on your own. It is in the book if you take the time. I don't need to do it in class. In the end you get a very simple solution." In this example, even without discussing the details of the problem Prof. Almond was solving on the board, it is clear that the textbook may serve as a resource to explain the steps skipped during lecture.

While this strategy may save time during lecture and allow for more conceptual physics discussion, not all students in the class actually felt confident in their ability to "do the math." A student, Gary, said in an interview that professors expected students to be able to do the math like algebra and calculus easily in physics problems, but that was actually very challenging for him[15]. Another student, Richard Feynman, who often earned top grades on physics exams, also reported that when he had mistakes in his homework, the problems usually arose from errors in the math, especially algebra[16].

In summary, instructors needed to take advantage of students' resourcefulness in upper division physics classes to move quickly through desired material set out in the curriculum. In many cases, it is likely reasonable to assume that most if not all students will be able to carry out certain procedures on their own at home. However, it is also common for students in the class to have difficulty with these components that are left out of class. As such, this pattern contributes to one of the ways and one of the reasons that upper division physics courses relied on a significant independent work component.

#### 3.3.2.2 Expectation That Students Already Knew the Material

Another reason instructors left expected work for outside of the classroom was that they believed that all students already knew the information or strategies of interest. As an academic rather than physics-specific example, Prof. Rice started the first class meeting by briefly discussing the printed syllabus with students[17]. She touched on some aspects of the syllabus but not others, stating that, "Other than that I assume you know how courses work and can read this on your own," before moving into lecture on tensor notation.

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[15] Interview June 15, 2017

[16] Interview June 14, 2017

[17] Field notes during lecture April 4, 2017

Returning to the example from October 27, 2016 with Prof. Walnut and the coupled oscillator, once eigenmodes were calculated and a student volunteered a physical explanation to make sense of the meaning of the solutions, Prof. Walnut resumed lecture by stating, “You all know very well that frequency is proportional to the square root of the spring constant.” In this example the frequency of oscillation of each of the masses corresponded to the previously calculated eigenmodes, or eigenfrequencies, of the system. Taking that value and relating it to the spring constant of the springs holding the masses together was the next step, and Prof. Walnut’s connection from frequency to spring constant consisted of a statement of fact. Contrary to the previous example about the course syllabus, this example does not show the instructor telling students to do something specific outside of class that they should already know how to do, but instead builds off of assumed prerequisite knowledge during class. For students who were not already confident that “frequency is proportional to the square root of the spring constant,” justifying this step or statement is left for independent work simply to catch-up.

Another example in this same category of “you should know this so I will not take time in class to go over this” comes from Prof. Almond’s lecture April 3, 2017. Prof. Almond stated, “This isn’t new. You learned this in general physics so I’m going pretty fast.” The instructor explicitly stated the reason for his moving quickly through material during lecture was that this material was also taught and learned in “general physics” or lower division physics courses typically completed during freshman and sophomore years that everyone should have completed already. The assumption then was that the material was already familiar to all students and that a quick review would suffice instead of a longer, more in-depth lecture. For students that needed to review that material, independent study was required to catch-up.

At the upper division level, instructors relied on the prerequisite courses as sources of knowledge or training for the students in their class. This seemed to be a necessary and reasonable design for a multi-year degree program, but presented challenges for students with very different experiences in their prerequisite coursework, which was sometimes completed outside of the Department of Physics (for example, mathematics) or at a different institution (such as community college), sometimes outside of California or the United States. In any case, the building up in each course from assumed starting points from previous classes created some need for independent work on the part of the students to discover what the expected starting point was and to adapt to meet that expectation on their own time.

### 3.3.3 Curriculum Calibrated to the Most Vocal Students

In almost every single lecture observation, the majority of class time was filled with the instructor speaking to the students about the class material. Often the lecture was peppered with short, straight-forward questions for students to answer in a single word or a short sentence, with answers like, “zero,” or, “up.” Vocal participation from students never exceeded 25% of the students in the class and sometimes was as low as about 5% of the class. When instructors would ask brief questions to the class at large, they usually would evaluate the first response they received and they had presumably been seeking and then resume lecture. Occasionally the instructor would evaluate a student’s response and then follow up with a new question for the class asking if “everyone” understood why the response was correct. Use of the term “everyone” seemed to be rhetorical as instructors never once required literally all students in the class to respond to a question unless written silently on paper and then passed forward, which was requested by only Prof. Wheat in his class during the second term of the year.

As a result of this common practice or style of lecture, the pacing of lecture was set to match the small subset of the students who were most willing to speak up during lecture. Responses from students typically came from a small fraction of the class who would speak repeatedly throughout lecture across many of their classes that I observed. Some of the repeat participators included Mark, Sycamore, John Snow, and others who did not participate in my study. For the majority of students who did not speak up during class, other strategies were used to make sense of the material. For example, small groups of friends would often sit together and whisper quietly to one another huddled over textbooks or notebooks during class, suggesting to me that they were trying to understand one part of lecture while the instructor continued. Another strategy possible for some but not all students depending on their schedules and other obligations was to attend office hours or problem sessions and ask questions about lecture or homework there. In all of these examples, students who were willing to speak up during lecture received feedback about their answers and questions while the majority of their classmates found other ways to catch up or explore the material on their own time.

## 3.4 Smartness

The popular culture association between physics and intelligence showed up in various ways throughout the data. Building decorations, class curriculum, faculty comments during lecture, and student beliefs all point to the idea that doing physics correlates with being a genius. In my personal experience living in the world, I am very familiar with a common and uncomfortable reaction from strangers when they find out that I study physics, which is to exclaim, “Wow, you must be smart.” The meaning of smartness as the concept appeared in this study was mixed across and within participants, varying from a fixed trait that a person either has or does not have to an accumulation of knowledge built up over time with dedicated practice. In this section, I will lay out the evidence that the notion of physics and smartness being linked played a role in the experiences of the physics majors at Sun University.

First, the famous physicist Albert Einstein lives on in popular culture as a notable genius. In language, Einstein is synonymous with genius (as in sarcastically calling someone Einstein who has just done something foolish). A Google image search for the term smart person yields a majority of pictures or caricatures of Albert Einstein. In the Main Building, large portraits or photographs of Albert Einstein hang on many walls, including in the Undergraduate Lounge, a conference room, and multiple hallways throughout the building. During an observation in the Undergrad Lounge, participants noted that the picture of Einstein had been moved from the center of a wall to a corner of the room. One person cried out, “Why did Einstein move?” Another commented, “He’s supposed to be in the middle.” A third person remarked that the movement of the portrait of Einstein was a sign[18]. The physics students in this example seemed to apply a religious connota-

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[18] Transcribed audio from Undergrad Lounge November 18, 2016

tion to the portrait of Einstein in their lounge, albeit in a joking fashion. The prevalence of imagery of Albert Einstein within Main reminds me of the more common practice in other settings to hang pictures of government leaders or religious leaders. Seeing pictures of Einstein on a daily basis emphasized the human, social element of physics more than a cold, rational, objective description of the discipline.

Next, the content covered in physics classes revolved around a set of core principles and relationships, typically named after the individuals who developed them. Part of learning the vocabulary of physics was to learn the names of the men who published their theories. Some of these names include Einstein, Newton, Maxwell, Planck, Boltzmann, Lagrange, Euler, Fourier, Hamilton, Laplace, Gauss, Ohm, and Kirchoff, among others. These names often represent concepts, for example, “Write the Lagrangian,” or, “Set the Laplacian equal to zero,” or, “Create a Gaussian surface,” or, “Take the Fourier transform.” In an interview with Mr. Pink, he joked that some of his classmates who were “killin’ it” by earning the highest exam grades in his physics classes were “possessed by Einstein or something[19].” He then joked that if he had a choice, he would prefer to be temporarily possessed by Lagrange in order to understand “what the hell he was thinking” related to a challenging topic in Analytical Mechanics 1 named after him.

Other connections between class curriculum and the historical figures whose names are used today come from faculty members during lecture. In her lecture on tensor notation, Prof. Rice commented that tensor notation greatly simplified the expression of some important relationships in physics, but that before that, somehow, Maxwell (known for “Maxwell’s Equations” that form the foundation for electricity and magnetism) was able to see relationships despite how difficult they were to see at that time without the benefit of tensor notation.

During lecture November 15, 2016, Prof. Walnut mentioned some articles he posted on the course website. He said the articles touched on:

> how resistant the mathematical community was, you know brilliant mathematicians of [Fourier’s] day, you know thought that this was completely ridiculous that we could expand any function in terms of sine and cosine.

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[19] Interview December 5, 2016

> How crazy is that they thought. But actually that proof is a simple construct of things that you know about Hermitian operators, namely that they have a basis, that their eigenfunctions form a basis. That guarantees that the Fourier series, Fourier's theorem must be true.

In this story, Fourier was positioned as knowing something then that we now know "must be true" but was surrounded by "brilliant mathematicians" who opposed him. Students in the class were presented with the end of the story, that Fourier was right all along despite the resistance, by simple fact that Fourier's Theorem was being taught in class. Deeper meaning of the story is not clear and likely different person by person, but one possible interpretation is that if Fourier was right and brilliant mathematicians were wrong, then maybe Fourier was even more brilliant than they were.

Without full history lessons or courses on the development of modern physics, students hear snippets like these infrequently during lecture. In this way, the snippets that get shared likely relate to the people whose names appear in the curriculum, like Maxwell and Fourier. Sufficient time was not devoted to discuss the complexities, collaborations, or non-linearities in the development of these theorems to paint a more relatable scene for students. The result is that students see a partial picture where historical physicists were simplified as smart people who advanced human understanding of physics at the time despite difficulties and opposition.

## 3.5 Motivation for Studying Physics as Desire for Theoretical Understanding

In lectures from many faculty members, value was placed on the simplicity of the relationships or solutions to problems and enthusiasm for the material was linked to the satisfaction of gaining a greater knowledge or understanding of how physical systems in the universe work. For example, Prof. Pistachio joked at the start of class one day that, "I know everybody was up until three in the morning losing sleep because you were bothered by this[20]." On a separate occasion, Prof. Rice joked during class that, "You may have heard of this before but you don't dream about it every night, hopefully not in

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[20] Observation during lecture April 7, 2017

nightmares[21]." These two instances relate the content from the physics class to something that may affect students' sleep from unavoidably thinking about it all the time. Topics in class were sometimes appreciated by instructors as "fun" or "beautiful," such as during an October 27, 2016 lecture by Prof. Walnut who remarked "it's a really amazing thing when a system of equations has a simple solution."

In these multiple examples of instructor speech during lecture, it seemed the instructor was sharing their enthusiasm for the subject matter. They joked that the topics from class should impact students' lives outside of class or remarked with appreciation and satisfaction about results from solving physics problems. The humor about sleep and dreams affected by topics from class suggested an almost complete dedication to physics during waking hours. In this next much more extreme example, Prof. Wheat spoke for nearly three minutes about the role of excitement and interest in the pursuit of physics for the sole purpose of understanding the universe better:

> That was a miracle that we discovered relativity before quantum mechanics. Wow. It's still astounding that all this mathematics led to a shift in understanding between spacetime itself and causality in the universe. It's worth pondering these things. I remember I asked a Nobel-Prize-winning physicist once about alternate interpretations of quantum mechanics. I'll never forget what he said. He said I think you should learn it first and then ponder it. And I felt like the air being let out. Like why the hell am I doing this if I can't have fun thinking about all the implications for philosophy? You need motivation to plow your way through these things and so I'm trying to help stimulate your imaginations and your questions. We've arrived at a place in physics now where it's starting to look like our relativistic quantum field theory is not really holding up too well. That we can't use the theory to calculate the Higgs boson mass is a serious problem. We need a new solution. I think a revolution is coming. I really do. It's exciting[22].

The strong emotive words like wow, astounding, fun, and exciting suggest that Prof. Wheat was deeply engaged and invested in understanding theory in physics. He explicitly stated that the students in the class needed motivation to get through the highly involved calculations in special relativity, and proposed that thinking about the implications of the

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[21] Observation during lecture April 6, 2017

[22] Edited transcribed audio from lecture March 2, 2017

results and contradictions in current physics knowledge could provide that motivation for students as it evidently did for him.

## 3.6 Conclusion to Chapter 3

Others [30, 24, 33] described having a wide variety of activities as beneficial to all students and a lack thereof as disadvantaging minority groups, and here we see an educational program that strictly adhered to a small set of forms of instruction and assessment. Teacher-centered lectures had students sitting for 50 to 80 minutes while homework assignments caused students to concentrate alone on impersonal learning stimuli, both of which fit within the analytical cognitive style described by [24] as potentially disadvantaging African American students on average. The lack of collaborative work and the competitive curves on exam grades fit with the field-independent learning style, which potentially disadvantaged Hispanic students on average. Physics lectures emphasized inductive and deductive reasoning and largely focused on details of specific examples and cases, disrupting the inferential reasoner who loses sight of the big picture in this method [33]. It would be a mistake to closely associate specific learning styles with ethnicity or race groups. Instead, the point is to identify that a lack of variety of activities and assessment creates a filter for the particular students who respond well to those formats. The concern is that the style of class and assessment were not inherent to physics as a discipline, but were culture-bound and historical, defining and privileging "traditional" physics students.

The purpose of this chapter was to provide a detailed description of the undergraduate physics program at Sun University, and to use evidence to establish the existence of a set of physics norms in this setting. In Chapter 4 we will look more closely at the most directly influential interface between the undergraduate degree program and the students: grades. In Chapter 5, we will place students at the center of our investigation, or at the origin of our coordinate system, to gain an understanding of the active work of the students as agents in their own education in the Department of Physics.

# Chapter 4

# Finding: Grades Impact Students

The research questions are:

1. In what ways do students' backgrounds and personal experiences interact with formal physics education? More specifically, which components of formal physics education mediate changes to students' attitudes and behaviors?
2. How do students take up and resist dominant modes of participation in physics?

This chapter addresses the first research question by focusing on one component of formal physics education that impacts students' thinking and behavior: grades, especially exam grades.

In Chapter 3 it was noted that timed, closed-book, independent, written exams comprised about two thirds of overall course grades across all six major junior year classes with five unique instructors: Mathematical Methods, Analytical Mechanics 1 and 2, Electricity and Magnetism 1 and 2, and Quantum Mechanics 1. In this chapter, these exams are described and discussed in greater detail and students' experiences with the exams are explored. Typically the average score on the exams was low, course grades were generously curved at the end of the term, and many students responded negatively to a disconnect between exam scores and physics learning goals despite passing the class.

## 4.1 Physics Exam Grades Were Low

Figures 4.1 and 4.2 show distributions of exam grades in the six major junior year physics classes during the first year of the study: Analytical Mechanics 1 and 2, Electricity and Magnetism (E&M) 1 and 2, Mathematical Methods in Physics, and Introduction to Quantum Mechanics. Figure 4.1 provides scores for midterm exams, with two midterm exams in each E&M 1 and 2 for a total of eight midterms across six required junior year physics courses. Figure 4.2 provides scores for final exams in the six required classes. The distributions include all students in the class, not just study participants, and were therefore de-identified. Unusual peaks in the range 0-10% in the midterms for Analytical Mechanics 2 and Math Methods and in the final exam for Math Methods. These likely represent students who either did not take the exam or did not complete the class for credit, and may not have been submitted to the university.

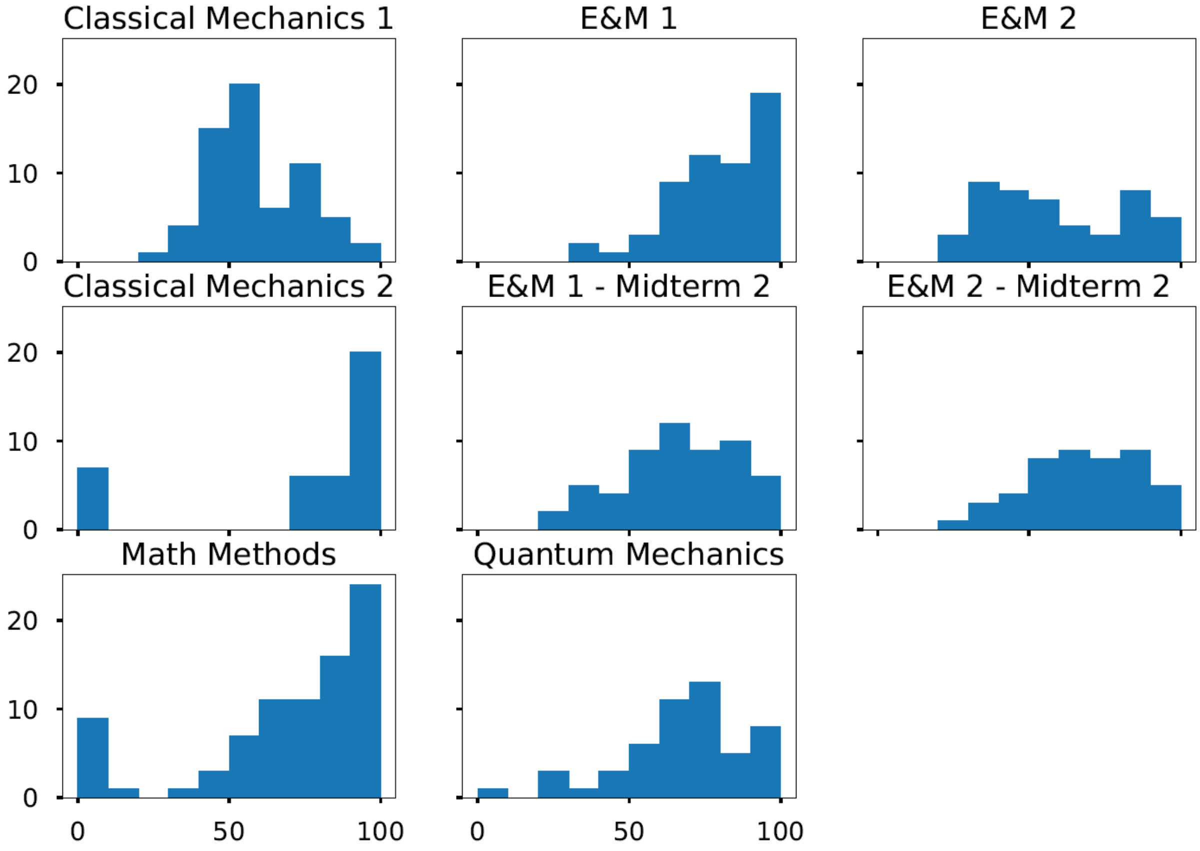

Figure 4.1. Histograms of the score distribution for each midterm exam from all six major junior year courses, including two midterms each in the two Electricity and Magnetism courses

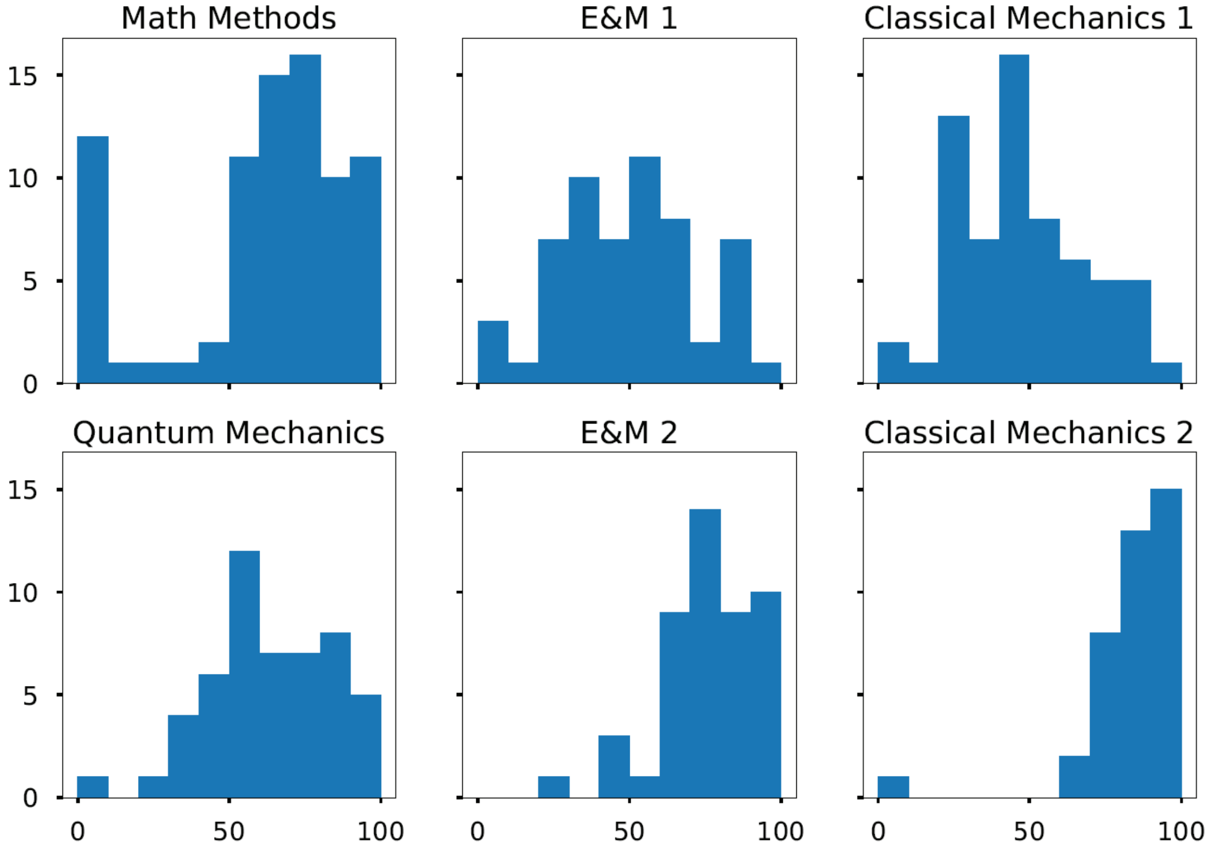

Figure 4.2. Histograms of the score distribution for each final exam from all six major junior year courses

The class that stood out from the rest as having distinct exam score distributions was Analytical Mechanics 2, taught by Professor Wheat. The most common score on the Analytical Mechanics 2 midterm and final was between 90-100% and aside from scores of 0%, no students scored below 70% on the midterm or below 60% on the final. Among the remaining classes, much broader score distributions were observed, sometimes with a significant fraction of the class scoring below a 60%.

## 4.2 The Meaning of Percentage Exam Scores Was Uncertain

In many academic settings outside of the Department of Physics at Sun University, participants learned a common translation from percentage score for an assignment and the corresponding letter grade or grade point average (GPA). The common translation in the United States is typically 90-100% for A-, A, or A+, 80-90% for B grades, 70-80% for C grades, 60-70% for D grades, and everything below a 60% for F, or failing grades. Considering the observation in the previous section that exam scores below 60% were common, the usual mapping from percentage scores to letter grades would indicate that failing physics exams and therefore physics classes was also common. On Sun University physics exams, however, percentage grades had no direct translation to letter grades.

Figure 4.3 illustrates the mapping between overall percentage in the class, which largely reflects exam performance, and the assigned letter grade submitted to the university for all enrolled students for five of the six physics major required junior year classes.

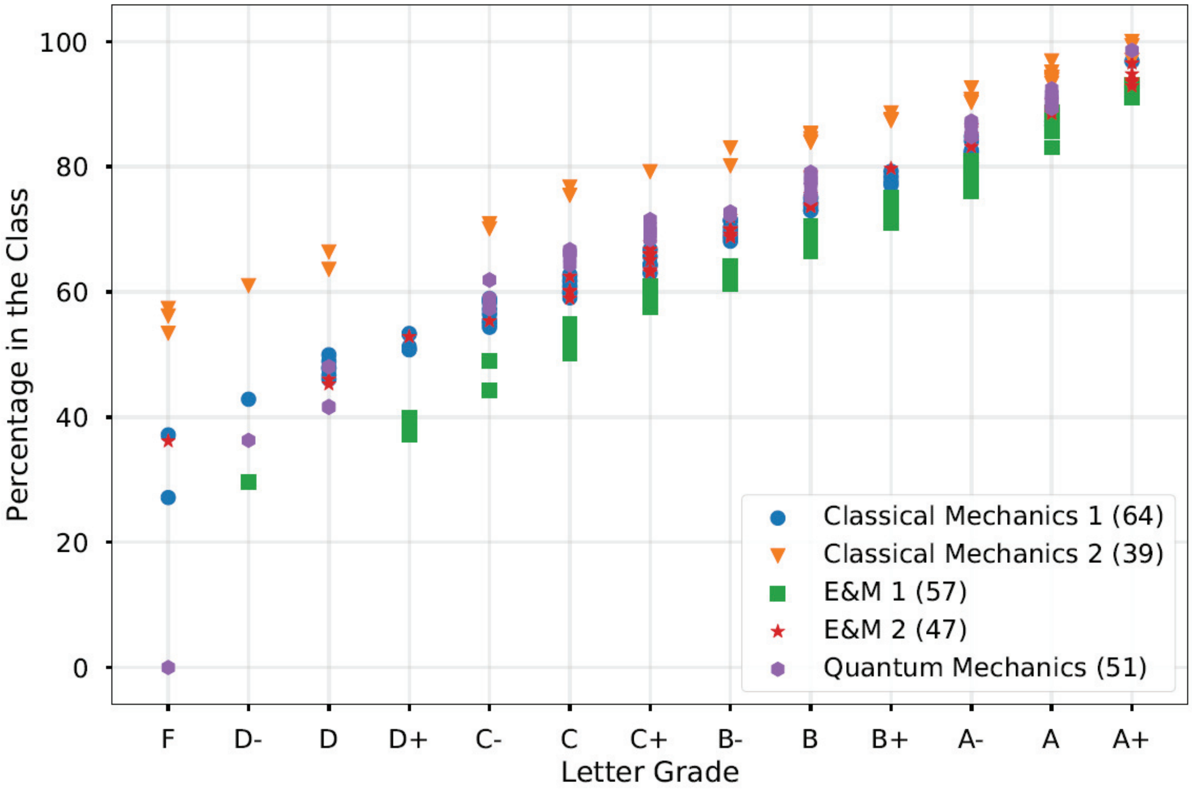

Figure 4.3. Relationship between percentage in the class and course grade for five of the six major junior year classes

The two classes that differed from each other by the largest amount were Analytical Mechanics 2 with Prof. Wheat and E&M 1 with Prof. Almond, which were both taught during the same academic term, the second quarter of the cohort's junior year. The mapping in Prof. Wheat's class closely followed the common mapping in the United States in other academic settings: A grades were roughly 90-100%, B grades were 80-90%, and so on. All students earning below a 60% in Prof. Wheat's class received an F in the class. By contrast, some students earning below a 60% in E&M 2 during the same academic term received as high as a C+ in the class by a process referred to by participants as "curving". Students earning an 80% in Prof. Wheat's class received a B- while students earning the same percentage in Prof. Almond's class that quarter were "curved up" to an A-. To look at it from another angle, take the range of percentages resulting in a C across the different classes. The lowest percentage grade earning a C was around 50% in E&M 1 while the highest was around 75% in Analytical Mechanics 2. The broad range of mappings between class percentage and letter grade severed the usual tie between the meaning behind letter grades and actual performance in the class.

During an observation in the back room of the Undergrad Lounge (See Figure 2.1), participants Mayzee, Jade, and Brian discussed interpretations of their E&M 2 midterm exam scores based on their percentage received and the mean and standard deviation of the distribution that Prof. Almond announced during lecture[1]. Jade reported that a graduate student and former TA, Eugene, offered advice on how to guess your letter grade based on this information and added that Prof. Almond told the class that the average would be about a B-. After that announcement, Prof. Almond started class without further discussion or interpretation of exam grades. Brian said the average was a 57% and the standard deviation was 22 percentage points. Mayzee asked if one standard deviation above and below the mean corresponded to one letter grade above and below the mean. Jade commented that Eugene had informed her that it would be one half of one standard deviation for a letter grade. Mayzee asked if that meant one half of one standard deviation above the mean would go from a B- to an A- or from a B- to a B. Jade said she was not sure, she did not know much statistics, and she should ask Eugene about this again. Mayzee said it was bad for her either way in E&M and laughed, indicating to me that she likely scored below the average of 57% on the exam. Knowing

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[1] Field notes from Undergrad Lounge May 8, 2017

that Eugene was not a TA for the course at that time, I provided additional information that another participant, Mr. Pink, had asked Prof. Pistachio about letter grades and standard deviations in Quantum Mechanics and that Prof. Pistachio said there was not a real cutoff for grades using standard deviations. Jade said the course grades were decided at the end based on all of the grades from the quarter combined. In summary of this conversation, participants were very unsure how to interpret their low scores given the mean and standard deviation of the class, and that the advice they received differed between sources.

Unfortunately, aside from exam scores, students did not receive very substantial commentary feedback about their performance. Participants commented that feedback on exams, which took the form of sparse handwritten markings like ‘x’s, check marks, and numbers typically in red pen, often did not clearly indicate how or why points were awarded or deducted. For example, Jade's graded midterm exam from Quantum Mechanics provided an example of common exam performance feedback. The midterm exam had four problems, each with three to five subcomponents. When full credit was awarded, the only marks on the page were the point values of each subcomponent. For example, 10/10 was written next to each of three problem subcomponents and the total score for the problem, 30, was circled at the top of the page. On a problem where Jade received 26 out of 30 total points, one subcomponent had a 6/10 next to it and a circle drawn around the subscript on the spin operator $\hat{S}_z$ with a note, “x, it's $\hat{S}_x$” indicating that Jade had mistakenly calculated an angle from the z-axis instead of from the x-axis as had been indicated in the problem statement. On the next problem, Jade received 16 out of 20 points for two mistakes. In one subcomponent, Jade mistakenly added 1 + 1 and found 1, but full credit was awarded on this subcomponent, indicating that arithmetic may be incorrect as long as the mistake is small, easy for the grader to identify, and does not detract from the demonstration of physics knowledge. The grader underlined the (1 + 1) in Jade's work and also wrote in a 2 in the appropriate place in her answer. On another subcomponent, Jade's multiple lines of work and small diagram were awarded 0 out of 4 points, with a note from the grader stating, “that's for spin 1; you have spin

1/2." This example is noteworthy because a blank page for this subcomponent would have received the same credit as Jade's work received. Again, the mistake in this case was in writing down an inappropriate matrix given the problem statement. Setting up a physics problem may be considered "the hardest part" as conceptual understanding is often required to translate the problem statement into something analytically solvable. Finally, Jade received 7 out of 20 points on the last problem. The only markings on the page were a 7 circled at the top, and 1/6, 4/8, and 2/6 written next to each subcomponent. No comments, 'x's, or check marks provided any hints as to how these point values were decided based on Jade's work.

My assessment of how this exam was graded is that (1) partial credit was awarded for solutions when work was shown in some cases but not in one case, (2) small math mistakes such as an arithmetic error were not penalized because the exam was meant to measure physics knowledge instead of math skill, and (3) little evidence existed to suggest that all exams were graded consistently and fairly. Perhaps all exams were, in fact, graded with complete consistency and fairness, however, there was no statement, rubric, or feedback that students received to indicate as much. Further, zero points were awarded for one problem subcomponent where work was shown, suggesting to me that students must weigh their confidence on a problem on an exam to determine whether the time spent working for potentially zero points is better than doing more to polish a solution on another problem in hopes of more credit there.

Given the format of feedback on exams, with little commentary from graders, a total score, and the mean and standard deviation of the class, students came away with unclear understandings of the meaning of their performance on exams in their physics classes.

## 4.3 Exam Scores Created Competition

Because exam scores below 60% were common for students in most of their upper division physics classes yet letter grades were more generous, reducing the number of students failing the class by curving, students were thrown in direct competition with one another. Letter grades were determined loosely for each student *not* on the basis of that individual student's performance relative to curricular learning goals but instead on the basis of statistical characteristics of the overall performance of the entire class of students. In the previous section, participants guessed at letter grades corresponding to their exam performance given the mean and standard deviation *of the class*. This meant that for the same student to do the exact same work on the exact same exam but in a cohort of much higher-scoring or lower-scoring classmates, the student could earn vastly different letter grades. The conclusion then is that grades in physics classes with low exam averages such as these were curved and therefore competitive.

Participants felt the exam-related competition with their classmates. Allison commented during an interview, "I know we're not supposed to compare our grades to everyone else but then again how can we not compare our grades to everyone else so I use my grades to gauge how I'm doing in the class compared to everyone else[2]." In an interview, Sycamore related a story about a tricky exam problem requiring knowledge of the law of cosines to get through the first step. She said that everyone was frustrated coming out of that exam, but that one classmate had known the law of cosines and was able to use it successfully on the exam. In a smiling and joking manner, Sycamore described her classmates as agreeing that they hated the one person who likely did well on the exam[3]. That a student's friends should joke about hating him for his success on an exam indicates a competitive environment, even if friendly. For a third example, a student who routinely earned one of the top five scores on exams, John Snow, reported discomfort in discussing exam grades with classmates[4]. When he did well on an exam, he would typically keep quiet about it until his classmates revealed their feelings about their own performance on the exam. If they did poorly, John Snow would keep his own score hidden and avoid talking about the exam with those classmates because he thought it would make them feel bad to discuss it with him.

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[2] Interview December 5, 2016

[3] Interview June 14, 2017

[4] Interview November 20, 2017

## 4.4 Exam Scores Discouraged Many Students

The combination of low percentages, unclear meaning, competitive curving, and lack of commentary feedback on exam performance negatively impacted students in the upper division physics classes. In an interview, Mr. Pink talked about how the start of his first academic term at Sun University involved a daily morning routine of going to the gym and having a good breakfast before class. Once midterm exam grades came back, however, his routine was wrecked[5]. Mr. Pink said that the low score on his Analytical Mechanics 1 midterm especially destroyed his confidence and caused him to spend more time working on problem sets and studying, leaving him with less time for sleep and causing him to abandon his healthy morning routine.

During a group discussion with Mayzee, Brian, Jade, and Allison, Mayzee lamented:

> The class averages are all like [...] in any STEM class fifty percent is average. Why can't you design a test where the average is seventy-five like normal and then we can at least feel good about it, you know? And instead we all get fifty forty sixty and we feel like crap all the time but really we did average. It's the most terrible feeling honestly[6].

With this remark, Mayzee expressed a constant feeling of discouragement stemming from the low grades on exams despite knowing that low grades may correspond to average performance relative to classmates. The number itself on the exams in physics classes was compared to common meanings of that number from academic contexts completely outside of the current physics class. Students carried with them the understanding of what exam scores meant from their past experiences with exams, which resulted in feelings of discouragement.

Many participants seemed to carry a belief that instructors expected that students should be able to earn full marks on their exams despite the fact that some instructors explicitly announced in class that they expected a certain percentage average score or that they expected the exam to be difficult to finish during the allotted time. Even though some instructors made statements about expected score distributions on upcoming exams,

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[5] Interview December 5, 2016

[6] Interview December 5, 2016

this strategy was ineffective at shielding students from the discouragement they drew from their low exam grades. Somehow, students associated the content of the exam with what they believed the instructor expected students to be able to complete correctly in the given time. For example, Mr. Pink shared his appreciation for Prof. Wheat's exam policy, declaring that Prof. Wheat "knows not everyone is a genius" and he gave "fair" exams with very high average scores[7]. Mr. Pink clearly associated performing very well on an exam as to-be-expected in the event that the exam was fair, whereas exams with low averages were flawed in the assumption that "everyone is a genius." As another example, Allison revealed that she believed exams represented what students were supposed to know during an interview, "And we get a C B or A in the end and then kind of feel like we maybe don't deserve it because we don't know everything or we don't know even half of what we're supposed to know[8]." With this comment, it seems Allison associated percentage score on an exam with percentage of the physics material that you know, where 100% on the exam meant that you knew everything *that you were supposed to have learned* in the class. In both of these examples, students evaluated the content on their physics exams as what they were supposed to be able to do, and so when they performed poorly and earned low percentage scores, especially those below 60%, they felt that they must not understand the material at the expected level and that the generously curved letter grade they received at the end of the course did not reflect reality.

As the group discussion with Mayzee, Allison, Jade, and Brian at the end of their first academic term at Sun University was such a rich source of data related to students' interpretations of exam grades, a one and a half minute excerpt is transcribed here in detail:

| Line | Speaker | Speech |
|---|---|---|
| 1. | Mary: | U::m do you/ would you, mind.. sharing a little bit more about the bad/ experience you had in office hours.. You don't have to\ |
| 2. | Jade: | ↑Mm |

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[7] Interview November 17, 2017

[8] Interview December 5, 2016

3. Mary: but, I’m interested to hear what happened
4. Jade: Well I mean, it was just’so it was right after our midterm/.. so:\
5. Allison: *Oh*::\
6. Jade: Like he had just given us our::, he had actually given us just’like two weeks later he gave us our tests back/.. and so::\ I was just like, °oh::\ (0.5) I was so I was already feeling down\’I’was’like.. this’this.. this isn’t really part\ but I just thought this was interesting’that’like.. so::\.. he gave/, he I think he gave the person before me/ he was like (1.0) you did you did a *great* job on your test like r::eally=
7. Allison: ↑Aw\
8. Jade: =really congratulations/ and then he gave me mine with like no comment/ cuz=
9. Mayzee: Oh::(h)(h)
10. Jade: =I had failed and’I’was’like oh that’s too bad=
11. Allison: Aw\
12. Jade: =that’s ok I don’t deserve\ a comment ok.. and’then whatever so we went.. continuing with the office hour/ and um.. I can’t remember.. it was like two different times in a row/.. um I had asked a ques::tion:: and then one of my classmates had just said like’they’were’like oh\ that’s easy\.. obviously it’s this and I was like oh=
13. Allison: Oh!
14. Jade: =it wasn’t obvious to me.. I’m so(h)rry=

15. Mayzee: =I also had a bad experience there kind of the same thing. First of all, she said she failed the test but, the class average was like 56 and she got ((whispered)) one point below that ((return to voice)) so she didn't fail. [She got a C basically

16. Allison: [((laughter))

17. Mary: [So the class average was failing=

18: Mayzee: =So she got a C. [Probably

19: Mary: [So then everything is cu::rved

20: Mayzee: Yeah.. So it wasn't fai(h)ling.

21. (0.5)

22. Jade: I mean [60 50 percent

23. Brian: [Isn't it crazy though if it's uh ((begin extended overlapping speech)) if it wasn't curved that the average person fails/ a test/ isn't that mean there's something not right going on like why need to curve it like *so much* when most people ↓ °I'don't'know

24. Mayzee: ((overlapping with Brian)) But, when the class average is that then he makes seventy-five percent or whatever that grade so you basically got a seventy-five=

25. Allison: =But I mean the percentage definitely looks like I mean I got ((end of overlapping speech with Brian)) a fifty-four:\

26. Mayzee: I got a forty-seven so mine wa- ok anyways

27. (0.5)

28. Allison: [((laughter))

29. Jade: [((laughter))

Allison's and Mayzee's vocalizations during Jade's narrative (lines 5, 7, 9, and 11) indicate the emotionally charged nature of the midterm exam in Professor Avocado's class, where "it was right after our midterm (line 4)" carried much more weight than a simple description of time and implicitly explained why Jade was already feeling down at the start of the office hour in her story. The sympathetic interjections ("oh" and "aw") indicate that Allison and Mayzee shared in Jade's negative emotional response to the midterm exam and wished to express that connection with her during the discussion. In line 15, Mayzee interpreted Jade's "failing (line 10)" exam score of 55 as "a C basically," and then in line 24 re-interpreted the score instead *as a different number*, a 75. Clearly the number value on the exam carried real meaning for these students if the actual number on the exam could be better understood as a different number according to their shared background experience at community colleges instead of Sun University. In line 23, Brian also shared his belief that the low scores really meant failure despite the fact that in the end the letter grades did not literally mean failing.

## 4.5 Conclusion to Chapter 4

In summary of this chapter, exam score distributions were broad and averages were low, the meaning of exam scores was unclear and differed between classes, curved grading created a competitive environment, and students drew a great deal of discouragement from the numbers on their exams in their physics classes. Students were willing to work and study hard and wished to truly learn physics, but the incongruence between performance feedback in physics with other academic settings in their experience created a rift and hurt their motivation for their physics classes.

Seymour and Hewitt similarly discovered the difficulty for students in reconciling their successful academic pasts earning high grades and tying those to their self-esteem with the low exam grades in STEM classes [27]. Students in interviews also reported the stress associated with not knowing what the standard was for performance in the class since it was tied to classmates rather than learning goals [27]. The drawbacks of competitive curved grading for student motivation and self-efficacy are highlighted again by the findings reported here.

# Chapter 5

# Finding: Students Created a Thriving Community in the Margins of the Department

The research questions are:

1. In what ways do students' backgrounds and personal experiences interact with formal physics education? More specifically, which components of formal physics education mediate changes to students' attitudes and behaviors?
2. How do students take up and resist dominant modes of participation in physics?

This chapter addresses the second research question.

To form a physics analogy for better or for worse, we may think of this chapter as a standard physics problem whereby small test particles of electric charge $q_i$ are placed within an electric field, $\vec{E}$. In Chapters 3 and 4, I described the electric field and the ways that this electric field influenced test charges within. Those chapters adopted a simplistic model which ignored the contributions to the electric field of the tests charges. In this chapter, we will zoom in on the test charges and take a more complex viewpoint to consider the influence of the test charges on one another as well as on the electric field in their local vicinity. In this analogy, the immersive electric field represents the culture within the undergraduate physics degree program and the small test charges represent the undergraduate students in the program. In the standard physics problem, the electric field creates a force on the particles, which completely explains their motion. Similarly, STEM education research often documents a harsh "weed-out" environment which attempts to explain the attrition of women and students of color from STEM fields. To consider the real-world complexities of placing charged particles within an electric field by allowing the presence of the charges to modify the electric field represents studying the ways in which the active student agents within the undergraduate program also modify the culture. Allowing test particles to emit non-negligible electric fields defeats the purpose of the test charge in the first place, and is almost never covered in physics classrooms. The test charges have a known, quantifiable, and fixed charge which interacts with the electric field, whereas properties of people are difficult to quantify and usually vary over time. In any case, the purpose of the analogy is to portray the simple electric field model as limited in its ability to explain the motion of multiple charged particles or particles with significant charge. The participants in this study definitely have significant charge.

Students took up academic physics norms sometimes with pleasure and other times at cost to themselves (Section 5.1), re-shaped physics norms to carve a space for themselves and their communities in the department (Section 5.2), and defied physics norms to create a more inviting and compassionate environment (Section 5.3).

## 5.1 Taking Up Physics Norms

Students take up academic physics norms successfully and at cost to themselves. This section draws exclusively from the experiences of junior transfer students in the cohort. Having completed college-level physics at other institutions before arriving, the group of junior transfer students was able to comment on the culture of the Department of Physics at Sun University by comparison, whereas students admitted as freshmen had already been immersed in the department culture for two years by the start of the study.

### 5.1.1 With Pleasure

In this subsection, the ways in which junior transfer students embraced physics culture at Sun University are explored. In each example, we see how students enthusiastically pursued physics-oriented goals and took pride in their accomplishments.

During a student-organized event for new junior transfer students, Mr. Pink as a senior advised attendees that office hours were extremely valuable for him during his first year at Sun University because he got to know professors on a personal level and they got to know him and have sympathy for him (there was laughter in the room when he described professors as people with emotions)[1]. Mr. Pink also related that he learned way more from participating in undergraduate research with a faculty adviser than he ever learned from classes, such as how to program in C++. From Mr. Pink's participation during this event, it is clear that he valued his time spent building personal relationships with physics faculty around tackling challenging material during classes and through undergraduate research.

During an informal encounter in the Undergrad Lounge, Sycamore related a story about how one of her younger siblings was once appalled that Sycamore did not know who a particular celebrity was. Sycamore laughed while saying that she replied, "Stop. I know who Isaac Newton is[2]." This humorous story was volunteered after commenting that she uses popular phrases that she would not use otherwise if not for her younger siblings rubbing off on her. In this example, Sycamore aligned herself with physicists by celebrating her familiarity with an important historical figure in physics and his work and distanced herself from the unnamed masses who follow celebrities. She prioritized scientific knowledge over familiarity with popular culture. In an interview, Sycamore later expressed deep enjoyment of argumentation around physics problems, which she began practicing after a rough adjustment to Sun University and the development of a network among her peers[3]. Sycamore described that she typically started homework on her own and collaborated with classmates as needed when she got stuck, but that her favorite part that she found to be the most fun was when different solutions could be argued with classmates. She described standing around a chalkboard in a group debating assumptions leading to different answers as providing great satisfaction. From these examples, Sycamore

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[1] Field notes from student event September 29, 2017

[2] Field notes from Undergrad Lounge May 8, 2017

[3] Interview June 14, 2017

demonstrated her enthusiasm for scientific knowledge, collaboration, and argumentation of solutions to physics problems.

Upon reflection of his first year at Sun University, Juan described the improvement in his grades over time, from consistently below the class average to consistently in the A range, as attributable to "learning how to learn[4]." The main differences in his approach to his coursework were getting over the fear of being wrong, shifting focus from studying individual equations to looking for relationships between entire problem solutions, and spending more time isolated from his classmates. Juan embraced the expectation that he would make mistakes, used mistakes as learning opportunities, and found the growth of his understanding to be a worthwhile reward for his effort. Juan stated that posted solutions to problem sets and exams were his most important study resource, more so than the textbook, because he could work backwards through the problem to understand the steps. Once Juan began dedicating many hours to studying physics in isolation, he felt more motivated to join the group of his peers and help others than he had felt when everyone in the group was "grasping at straws" together. By the final academic term of his junior year, Juan felt the classes were harder but that he was more capable of success than he was upon arrival to Sun University. At the end of the interview, Juan concluded that the year had been "really gritty and rough" but that he was glad he took the time to learn physics, which had always seemed completely unapproachable among sciences when he was younger. Juan developed a useful strategy of searching for "transitions" between physics problem types to improve his understanding and was motivated by his ability to help his classmates after working at length on his own.

These and other examples indicate that participants experienced positive and desirable changes after arriving at Sun University, such as improving their comfort and skill in physics (problem-solving strategies and computer programming) and collaborative techniques with peers and with faculty.

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[4] Interview June 15, 2017

### 5.1.2 At Great Cost

In this subsection, the ways in which junior transfer students pursued the norms of physics culture that simultaneously forced the sacrifice of other important values are examined. In these examples, some particular elements of this academic setting demanded compliance from students who made changes in their own lives to adapt.

A participant named Angry Hamster[5] shared her experience of culture shock upon moving to the locality of Sun University[6]:

> You know when I moved up here I had to really adjust my language and how I speak and what I say and how I say it because I come off especially aggressive in [Sun University City] you know? [...] I have to work at swearing less, but that's turning something on that's not me and it's tiring. I can't keep that up for fourteen hours with peers. [...] I talk fast and loud and I try to scale that back because it's a little much for people.

Although Angry Hamster noticed the mismatch between her own family culture and physics culture at both Sun University and at her former community college, she also felt comfortable in it because she could see the people as "wonderful, awesome people." Aside from differences in style of language and topics of conversation between her hometown and Sun University City, Angry Hamster noted that the biggest barrier for her getting into physics had been her low income background. In order to be competitive on exam curves with classmates "who never had to manage their own lives or work," Angry Hamster saved up money for ten years and sought out financial aid to permit her to study full-time for the duration of the bachelor's degree after transferring to Sun University. In this case, the student underwent a transformation in lifestyle to succeed in the program while developing strong and important relationships with classmates.

In an interview with Mr. Pink, a recent exam came up where he left many problems blank because he "didn't know what the hell to write" even though he knew that partial credit "even for a bullshit answer" would have been better for the grade than leaving the question blank[7]. He talked a little bit more about his discomfort with writing on an exam when feeling unsure of the correct approach:

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[5] A pseudonym

[6] Interview November 22, 2017

[7] Interview November 17, 2017

> Physics is not bullshit. You shouldn't be writing bullshit answers but you have to. I don't know, it feels a little dirty but at the same time I want a good grade on an exam. [...] Physics is not based on bullshit but here I am.

Mr. Pink and I share this description of attacking a problem on an exam despite uncertainty in an attempt to earn sufficient partial credit to pass as "bullshitting." Despite our shared displeasure, we both have also implemented the strategy to succeed in our physics classes and degree programs. As a physics graduate student I have come to understand the strategy as actually the one that physics faculty expect you to take in problem-solving on exams: attack the problem with everything you got and make rough simplifying assumptions to change the problem from how it was actually written into something more easily solvable. To Mr. Pink and to me it *feels* wrong to treat physics problems in such a rough manner when we would rather do it right, according to our values of objectivity, thoroughness, carefulness, and accuracy. In Prof. Wheat's class where exam averages were much higher than in other physics classes, Mr. Pink's below-average performance garnered particular attention from Prof. Wheat, who told Mr. Pink that he knew that he could perform better than that. In this example, the student was forced by the forms of assessment in all of his physics classes to adopt a mindset that he viewed as inconsistent with physics as a discipline.

During the same conversation, Mr. Pink also told me about how when he spoke to his extended family members living in a Latin American country, they told him he spoke Spanish with an American accent, which he said hurt to hear. I asked why it hurt, and he said that Spanish was his first language so he expected himself to speak with a proper accent and grammar, but mainly, "It reminds me that I let something slip that was important to me." This experience of letting aspects of life aside from physics slip upon entering the degree program at Sun University was shared by many other students as well.

The examples shared by Angry Hamster and Mr Pink represent broader patterns in the experiences of junior transfers in physics at Sun University, that (1) they needed to align their language and behavior with the dominant academic culture in order to fit in with classmates and instructors and succeed in classes, and (2) dedication to physics in this intensely focused, fast-paced academic environment caused other important features of their lives and identities to fall by the wayside.

## 5.2 Reshaping Physics Norms

In many ways, students worked within the organizational structures of the department while bringing in themselves and their values to improve the culture without radical transformation.

For example, the undergraduate equity and inclusion in physics group, EIP, was formed in fall 2016 according to university policy and became an officially recognized student group on campus, with a constitution, bylaws, officer positions, and elections. When this student group actively engaged faculty members in their discussion about department climate, students reserved a room through the main office, announced and advertised the meeting time, and gathered within a classroom in the Main Building during business hours on a weekday. However, by reaching out to faculty members to raise the conversation about department climate and by sliding printed letters about the importance of this topic under the doors of faculty members, the students bent and reshaped the rules of normal operating procedures around meetings in order to seek change.

As another example, students raising their concerns with faculty members experienced very little response when faculty members saw the problem, such as mental health, as isolated to the individual bringing it up. In response, EIP initiated, designed, and administered their own mental health survey by visiting physics classes in session. This action simultaneously responded to faculty distance and inaction while operating within the normal boundaries of the scientific method and quantitative evidence that are valued in physics. The other major undergraduate physics group, Physics Society, also resisted normal faculty decision-making procedures around possible reallocation of the space for the Undergrad Lounge by collecting quantitative data on the use of the room by students for academic purposes. A survey students used to learn more about transfer students in the department is included in Appendix C. In these examples, student organizations advocated for themselves to the faculty decision-makers about department goings-on by using quantitative data to support the student perspective and stance where it was not solicited.

Mr. Pink, Brian, Angry Hamster, and Juan all independently in interviews emphasized their interest in physics and values of hard work and dedication to describe their position within physics despite the fact that they do not consider themselves to be brainiacs or standard "math and science people". These descriptions were often coupled with the sentiment that not only elite smart people should be able to pursue physics, but instead the people who have a deep interest in physics and are willing to work hard should also have a chance of making it. In one aspect, passion and enthusiasm for physics represent the norm. These students leaned heavily on this characteristic in thinking about themselves within physics. In the other aspect, dedication and hard work are not as stereotypical for physicists as innate brilliance [18]. By separating themselves from the stereotypical intelligent physicists, these participants created a separate way of being a physicist that is just as worthy and more attainable after having already been born.

Mr. Pink said that he has been struggling in physics all his life (in reference to difficulty with a physics class at his community college) and that "physics is dope[8]," but that "I definitely would not label myself a smart person." Similarly, Brian stated:

> For me I was an adult that chose to go to school and do math, people call me crazy for doing that, maybe I am. [...] Other classmates are surprised how much I study. I study all the time. I sacrificed a lot to get where I am. I do not consider myself to be a math or science person. More a stubborn person. I don't want to give up[9].

Brian claimed to not be a member of the group of people who could be considered "math or science people," who he described earlier in the interview as those who were brought up with an academic, science and math focus and who succeeded easily in his upper division physics classes without putting in as many hours as he did studying. Brian emphasized a different aspect of his experience, stubbornness, to supplement his interest in physics in place of the "brainiac" quality of some of his classmates. Another non-traditional student over the age of 30, Angry Hamster, stated in an interview that the only reason she has

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[8] Interview December 5, 2016

[9] Interview June 15, 2017

been able to succeed in physics was, "what I call stubbornness but what my mentor calls perseverance." Further, in interviews in December of 2016 and June of 2017, Juan described how he has always had a general interest in STEM but changed majors a few times before settling on physics. In comparison to two of his high-scoring classmates, Richard Feynman and John Snow, Juan explained that they knew beforehand that they wanted to go into physics and so they started more specific preparations for physics earlier than he had. He said that it does not bother him that they have trained themselves for physics more properly than he had. Juan explicitly stated that he doubted the prospect of naturally smart people aside from maybe little genetic advantages, because he saw skill as the result of effort and a good work ethic. Juan therefore positioned himself within physics as having a great interest and work ethic rather than a fixed trait of being smart.

In the examples with Mr. Pink, Brian, Angry Hamster, and Juan, all four discussed extensively the influence of parents and the home environment growing up for creating extremely academically minded and focused young adults who succeed in undergraduate physics more quickly or with apparently less trouble. While the participants saw their classmates who were earning higher grades in homework and on exams as having a desirable academically focused upbringing well-aligned with the program in physics, they distinguished themselves from that group as having a different background, but aligned themselves with another desirable aspect of being a physicist, which was interest and dedication.

## 5.3 Rejecting Physics Norms: Let's *Not* Be Robots

The first time that I met Juan, he introduced himself to the room at an EIP general meeting in the fall of 2016. When describing his reason for attending the group meeting, he described one of his interests in joining the group as, "Let's *not* be robots, how 'bout that?" He and many others in the room laughed and then introductions continued shortly afterwards. In an interview at the end of that academic year[10], I raised this point with Juan again. He further described the state of "not being a robot" as socializing and developing social skills. Juan explained that even though "social skills are not a physicist's

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[10] Interview June 15, 2017

strong suit," social skills take practice and learning from mistakes to develop, just like skills in physics. If someone is a robot, they may be at their peak in physics, but they do not have a balanced skillset, which Juan strived to maintain. I told Juan how "Let's not be robots" had stuck with me throughout the year and came to mind whenever I felt dissatisfied with the manner of interaction between people in physics as a way to chastise rudeness while simultaneously inviting greater compassion. We laughed and he said, "I'm glad it stuck." Juan also reported that he would be taking on an officer position within EIP during the upcoming academic year because he felt motivated by the goal-oriented focus of the group and the combination of work he felt was important with socialization among group members.

That Juan joined the physics major at Sun University and at the beginning of his first academic term after transferring already felt passionately about rejecting the robot-like state of an extremely narrow focus on studying physics, means that he likely enrolled at Sun University with ideas already formed about what physicists are like from his own experience at community college and earlier. Despite this image of the physicist as robot, Juan enthusiastically undertook physics studies while refusing to sacrifice other qualities that were important to him, such as strengthening social and communication skills. This example feels so positive to me because Juan did not harbor ill will towards his classmates who were excelling in physics classes; he described that their background preparation had been more focused on physics than his had been, and that he wished to succeed according to his own values system, which emphasized a well-rounded, balanced skillset.

The student-created, student-run Equity and Inclusion in Physics group (EIP), served as a primary hub of resistant thought, speech, and action for undergraduates in the Department of Physics. The group was founded by junior transfers and since its formation, the majority of officers and group members have also been transfer students. One of the founders and officers of EIP, Turk, explained that when she transferred to Sun University, she struggled with the lack of community and feeling isolated and overwhelmed. She developed important friendships with other transfer students in her cohort who were able to come together to succeed in their classes. Turk explained at an EIP general meeting in the fall of 2017 that she and the other founders of the group wished to create a more inclusive department environment for new transfer students in opposition to the experiences they had joining the department[11]. The formation of EIP challenged the standard operating procedures of the department by explicitly acknowledging and inviting junior transfers to join a community rather than struggle independently. Further, the activities of the group continued to critique normal physics standards in favor of reaching out, inviting, and demonstrating different ways to do physics and be physicists. For example, EIP group members collaborated with graduate students on three grant proposals for projects meant to innovate Sun University campus diversity efforts. Two of the proposals made it to the final round, requiring a short presentation open to all community members for consideration and voting. Finally, one of the EIP grants was selected and awarded funding! The project that the undergraduates proposed was to travel to local schools and community colleges to distribute information about non-traditional pathways into STEM fields, among other outreach activities. Students created an outreach pamphlet (Appendix E) as part of this project.

The pamphlet provided a particularly rich example of acknowledging and rejecting physics culture in three ways. First, the pamphlet was written in English and in Spanish, with both languages present on every copy, defying the prestigious English only academic system in favor of deliberately including multilingual and Spanish only speakers in the community. Second, the content of the pamphlet addressed pay for jobs in STEM, community colleges, resources for low income students, the growth and fixed models of intelligence, and stereotype threat and imposter syndrome. As interest and passion for physics remain the most noble reasons for entering the field, mentioning pay for STEM jobs and resources for low income students in the pamphlet addressed the practical reality for community members who do not see themselves as able to afford a career of interest. To highlight that STEM jobs offer rewarding salaries is an invitation for practically minded people who do not see themselves as geniuses to consider studying in STEM. Highlighting community colleges as pathways into STEM emphasizes a nontraditional and

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[11] Observation October 6, 2017

less prestigious trajectory as practical and viable. Identifying fixed and growth mindsets and offering strategies for moving towards a growth mindset of learning deliberately defies the stereotype that physicists must be natural geniuses in order to succeed. Addressing stereotype threat and imposter syndrome offer external reasons for challenges to arise for students studying STEM that to do not imply any deficiency on the part of the student. Every aspect of the content in the pamphlet reflected upon traditional, elitist physics education and argued against this standard. Third, the pamphlet was designed for students and for their parents and families to read, inviting in the entire community to think about education and careers in STEM in opposition to the culture of highly motivated individualistic learning. These oppositional strategies implemented in the creation of the pamphlet were openly discussed and planned among participants at organizational meetings during the spring of 2017 after the grant was awarded.

Another way that EIP rejected physics culture was found in the manner of running their group meetings. For example, EIP officers organized a welcoming and orienting event for new physics transfer students at the start of the 2017-2018 academic year, when the cohort of juniors participating in this study advanced to their senior year. Participants Turk, Juan, Mr. Pink, Lupo, Jeremiah, and Angry Hamster attended and co-led the event. As the entire group of EIP officers led the meeting in a turn-taking or panel-like fashion, they contrasted their management style against what was typical in their classes, where one faculty instructor or graduate student TA led discussion or directed the manner of participation of students. They tackled the meeting as a group instead of relying on a single leader. Further, the meeting took place in Main Lounge (Figure 5.1) with all chairs arranged in one large circle around the perimeter of the room. The event was popular and the lounge filled up a great deal. As Turk and I went across the hall to Classroom 101 (Figure 5.2) to get more chairs for the lounge, she asked if we should move the meeting into the classroom where there were more seats. In a matter of a few seconds, Turk, another EIP officer, and I decided against moving the meeting because the atmosphere in the lounge was good whereas Classroom 101 was known for "killing the vibe" because of the rows of forward-facing chairs where participants do not get to see each others' faces,

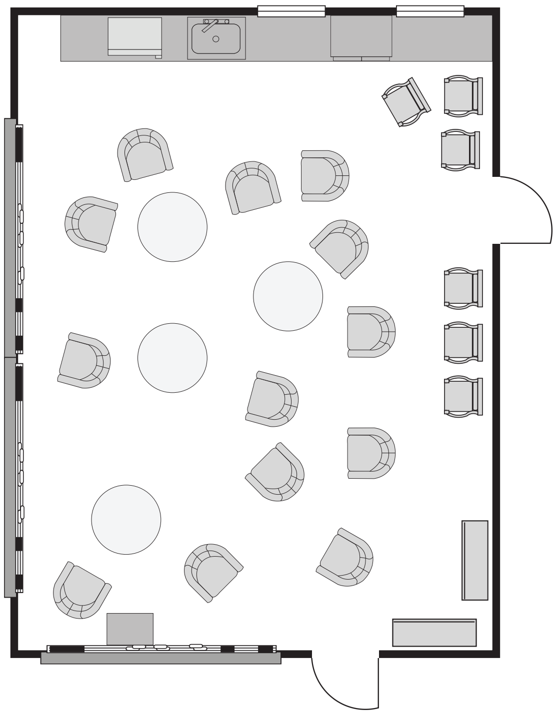


Figure 5.1. Illustration of Main Lounge

only the faces of the person or people standing at the front of the room. Further, even the content of the meeting was not decided solely by the group of EIP leaders. Instead, various officers proposed possible topics of discussion or activities, and then Turk invited everyone in the room to indicate their preference for how to proceed. After a vote, the original proposed agenda for the meeting was disregarded in favor of focusing on what the new transfer students wanted to cover, which was more questions and answers about experiences with classes and advising in the department. An additional component of the meeting that was not common in other settings in the department was the way students handled multiple speakers. When more than one person would start to speak at a time, one person would typically continue speech and others would stop talking. Usually there

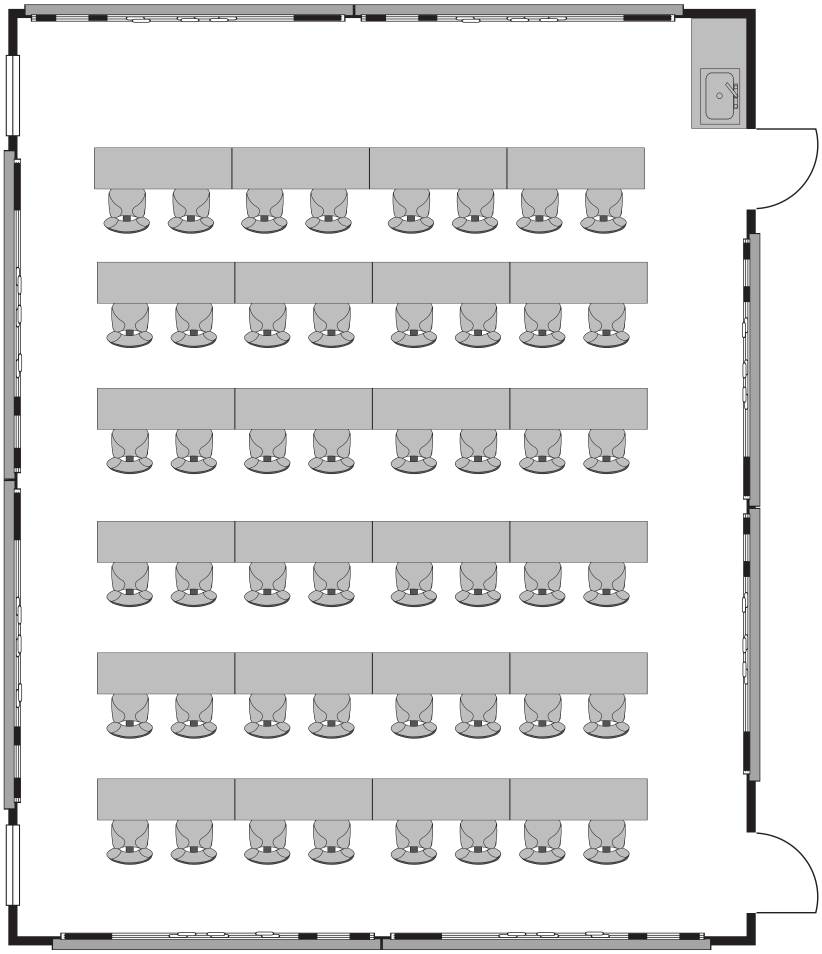


Figure 5.2. Illustration of Classroom 101

was some acknowledgement among multiple speakers and they would agree on who would continue speaking. This was not unusual in the department, however, the active memory of the room about who ought to speak next was uncommon. If one person who refrained from making their comment did not soon have a chance to speak again, EIP members would silently point at the that person. In contrast, when multiple physics students were working around chalkboards together, no such turn-taking was emphasized. In this EIP meeting, teamwork was used to support individuals and to make space for each person to be heard. When there were few other opportunities for students to be heard in their classes, EIP meetings served an important and oppositional purpose.

## 5.4 Conclusion to Chapter 5

To return to our analogy of the electric field and the charged particle, we now see the variety of strategies that the test charges deployed to take ownership of their motion, such as modulating their own charge and interacting with additional fields like magnetic fields and gravitational fields. The simple model of the electric field fails to explain the motion of the particles. At this stage, even modeling these particles as test charges is ridiculous. Similarly, to ignore the active thinking and doing of the students or to take a passive deficit model viewpoint of their challenges in the undergraduate program is not useful to describe their complex experiences, choices, and behaviors. Clear incentive exists for academic institutions to invest in developing a more full understanding of the strengths of their marginalized students; to turn away talented and promising physicists by using standards which have not been validated (Chapter 4) and which fail to capture the knowledge, skills, and community cultural wealth [36] of the students is an injustice and a disservice.

# Chapter 6

# Conclusion

## 6.1 Discussion of Findings

Chapter 3 described patterns in behavior and social norms which were revealed through careful, repeated observation and interaction in the setting. Chapter 4 examined the most prominent interface between the setting and the participants: grades. Chapter 5 finally placed the focus on the students as active agents in the setting, with the capability of reshaping and defying physics norms as well as embracing some aspects of them. As a whole, the undergraduate physics degree program at Sun University was set within an active community consisting of varying beliefs and values where power rested predominantly in the hands of faculty. The students learned the ropes, responded to challenges, and experienced an immense amount of stress that was largely unseen by faculty during teacher-centered lectures. From this study, we have a glimpse of the vast knowledge and skill resources available to students that were underutilized in their physics classes.

Finding a good match between a student and a university or between an employee and an employer is often emphasized in applications and admission or hiring processes, however, instructors of large classes had little opportunity to learn the backgrounds of their students to adapt the course to the particular group. The cohort I followed included transfer students from many different community colleges, freshman-admits who had taken distinct introductory physics series, and non-physics majors. Given this diversity in academic training alone, a clear challenge for instructors was to offer guidance for students to move towards a shared set of knowledge and skills. Instead, for many reasons like content coverage and university policies, instructors introduced new material relying on a set of assumed prerequisite knowledge and moved quickly along without much time for catch-up.

Students were dedicated and extremely interested in physics, but their motivation for their coursework was worn down by the obstacles and barriers that were unrelated to physics content, such as scheduling conflicts, independent learning, and competitive exam grading. Annoyance and displeasure suggest to me a mismatch of expectations. Typically two people can work through these mismatches with explicit communication and patience. In the case of the Department of Physics at Sun University, the power imbalance put most of the work on the students who responded to the burden using a variety of strategies, sometimes concluding that they no longer wished to pursue physics in the long-run.

## 6.2 Future Work

From this body of data, I plan to pursue more detailed and extensive investigations of the trajectories of each individual participant in the study. I would like to compare decision-making between students and summarize major motivating factors influencing activities and career plans. Creating closely marked transcripts of a larger quantity of recorded data will also assist in the discovery of finer patterns in beliefs and social norms among the cohort.

Important future work that I feel needs to be carried out is the creation and evaluation of physics education programs that are re-imagined according to a distinct set of cultural values from the current academic system in the United States. International studies would be extremely valuable. Finding effective ways to invite and include knowledge and skills that are currently mostly filtered out from careers in physics will enrich society.

# Appendices

# Appendix A

# Code Book

Table A.1 provides descriptions for the most heavily utilized themes in coding the data, which emerged over time throughout the iterative data analysis process.

| Theme | Description |
|---|---|
| Being right | Whenever "being right" or "correct" or "true" or "accurate" comes up as a reason for an action, choice, strategy, or influences what someone says. For ex: Someone re-writes something because they wish to correct a mistake |
| Choice | Whenever people have open or multiple options. Happens in problem-solving when choosing between approaches or strategies. Happens when deciding how to proceed with anything open-ended, like whether to redo something or deciding which information to present in a solution. Instructors make choices about which material to cover and in how much depth, what to assign problems on, etc |

| | |
|---|---|
| Community college | When participants share experiences from or about their community colleges or when anyone talks about community colleges as a concept or in general. May also be when participants talk about their transfer experience or something they explain as related to the fact they transferred |
| Connection between concept and equations | Talk about meaning of equation, concepts involved in lecture or problem-solving, attempt to understand what equation is saying or how it's used, significance of notation |
| Dislike | Negative words (annoying, gross, disgusting, hate, avoid) to describe something found to be unenjoyable in physics, like intense algebra or some special topics or strategies |
| Distinguish math from physics | Math operations are separated from physics problem-solving or expression. "Just math from here" is common. Or math is a tool for physics but is not physics itself. Opposite: Math is incorporated within physics as the way to express physics knowledge or to carry out physics work |
| Easy or simple | Simple derivations, proofs, solutions, concepts. Easy operations. Often a reason for choosing one problem-solving strategy over another. Sometimes used for intended reassurance, but may have consequence of making others feel stupid if it's not also easy for them. |

| | |
|---|---|
| Effects of power differential | Given speaking privileges, using titles instead of first names, direction of thanks, distance of relationships (knowing names, what to call each other), manner of addressing one another (formal vs informal speech) |
| Exams | Talking about or doing activities related to midterms or finals in classes |
| Gender | Explicit or implicit impact of gender noted: Implicit can be when theres some notable distinction in speech or participation seemingly according to gender differences known from other interactions |
| Growth mindset | Belief that abilities can improve over time with practice |
| Homework | Talking about or doing activities related to assigned problem sets |
| Independent learning | The importance of understanding for oneself or of studying or working outside of class |
| Instructor mistake | Students ask about or point out mistakes on the chalkboard and the instructor responds during class |
| Learning | Discussion of having learned something, or how to learn |

| | |
|---|---|
| Meaninglessness of exam scores | Ways in which exam scores reflect things other than true physics understanding, such as tricky questions, or a set of problems that is not representative of the content or level of difficulty in the class |
| Memorization | Need to memorize information for any purpose, typically exams or the GRE, especially for the purpose of speeding up problem-solving |
| Physics defined | Important or recurring concepts or strategies inherent to physics across many types of problems and subfields, for example: physical symmetries make analytical solutions much simpler than a general case |
| Physics outsiders | Patterns in speech, behavior, interests, or pursuits belonging to those who are not "physics people", for example, talking about the appearance of someone at a recent party |
| Problem-solving | Working through a clearly defined initial setup using known tools or strategies from class to reach a known and desired endpoint |
| Race or ethnicity | Explicit or implicit impact of race or ethnicity noted: Implicit can be when theres some notable distinction in speech or participation seemingly according to race or ethnicity differences known from other interactions |

| | |
|---|---|
| Smartness | Concept of being smart is discussed, but the type of smartness, meaning, and whether smartness can change over time varies within this theme |
| Stereotypical physicist | Characteristics closely associated with physicists are mentioned in connection to people in physics or are understood to be common for physicists, for example, social awkwardness and smartness |
| Students don't talk during lecture | In lecture, when students quiet down or when instructor asks a question but there are few if any responses. This is like the theme of the ”participation surface tension” where students' questions cluster in time |
| Students questions | Started as students come prepared with questions: Indications that students feel they must prepare before interacting with instructors, tutors, friends, or collaborators. Now it's also just used when students ask questions. Instructor mistake is used instead when a student points out a mistake during lecture |
| Teacher-centered | Activities or conversation with undergrads is controlled by one person who is a grad student or faculty |
| Team leadership | Whenever a group has gathered and control over time to speak or topics of discussion is shared among multiple people instead of one primary leader |

| | |
|---|---|
| Textbook | Whenever the textbook for a class is discussed or utilized, for example, using conventions in the textbook, or relating feelings of dislike towards a textbook |
| Time | Related to time: start/end time of class, due dates, deadlines, longer timelines like employment or overall degree |
| Undergraduate research | Whenever students are encouraged to pursue undergraduate research in the department or discuss their experiences getting in to research or what its like or what they have learned from it |
| Vocabulary | Instances when physics-specific, non-common language, vocabulary is used possibly sidestepping a more thorough conceptual discussion to get through problem-solving, for example, centrifugal |

# Appendix B

# Transcription Conventions

Table B.1 provides a key to symbols used in transcripts throughout the document.

| Symbol | Example | Meaning |
|---|---|---|
| - | watermel- | Truncated speech |
| ’ | It’went’fast | Quickly connected fast speech |
| = | You did fine=<br>=But I mean | Latching, a second speaker begins immediately after the first without pause |
| [ | No [it didn’t<br>[Yes it did | Overlapping speech |
| :: | so:: | Elongated syllable |
| .. | wait.. | Noticeable pause for less than one half-second |
| ( ) | (1.5) | Pause, rounded to the nearest half-second |
| , | but, | Short pause with level intonation as if to continue |
| . | end. | Short pause with falling intonation and finality |
| ! | hey! | Animated speech |
| italics | *emphasis* | Emphasized speech |
| caps | LOUD | Speech at a higher volume than surrounding speech |
| ° | °quiet | Speech at a lower volume than surrounding speech |
| / | rising/ | Rising intonation, similar to a question |
| \ | falling\ | Falling intonation, similar to a statement |
| /\ | ohh/\ | Rise-fall intonation, similar to how enthusiastic students say “ohh” when they understand something new |
| \/ | aww\/ | Fall-rise intonation, similar to expressions of sympathy, disappointment or sometimes cuteness |
| ↑ | ↑high-pitch | Begins at a higher pitch than previous speech |
| ↓ | ↓low-pitch | Begins at a lower pitch than previous speech |
| (( )) | ((mumbling)) | Description, not heard literally in the recording |
| (h) | lau(h)ghter | Exhaling while speaking, similar to laughter |

# Appendix C

# Artifact: Transfer Survey

This short survey is intended to asses what changes would best help transfer students adjust to physics classes at Sun University. It is anonymous and completely voluntary. Feel free to skip any question, but we ask that you please answer the first two.

When did you transfer to Sun University?

What grade level are you in?

Would a senior transfer student mentor have been helpful to you in your first quarter?

Was the Transfer Packet helpful in providing you with information about the Department of Physics?

Was the Transfer Meet and Greet helpful in preparing you for your first quarter?

Is there any information that you have since learned in your first quarter that you wish were provided in the Transfer Packet or Transfer Meet and Greet?

What was the most difficult adjustment from Community College to classes at Sun University?

What resources from student groups would be most helpful for new transfer students?

- Textbooks loan system
- Mentorship
- Tutoring (in addition to Open Help Sessions)
- Events for the transfer community

- Events for the physics community
- Other:

What resources from Professors were most helpful in classes?

- Problem sessions
- Office hours
- TA office hours
- Supplemental reading material
- Lecture
- Lecture notes
- Other:

What additional resources from Professors were/would have been most helpful?

- Discussion sections
- Additional office hours
- Additional TA office hours
- Posting lecture notes online
- Providing links to outside resources (Youtube videos, excerpts from additional textbooks, etc.)
- Other:

What resources from the department were most helpful in your classes?

- Degree requirement checklist
- Advising

- Open Help Sessions
- Undergrad Lounge
- Other:

What suggestions do you have to make Open Help Sessions a more useful resource?

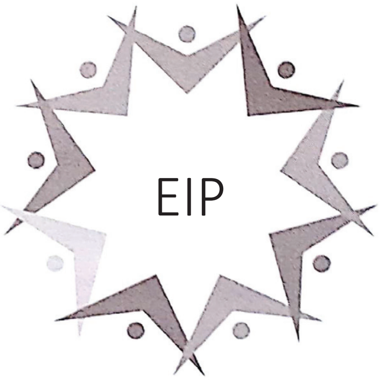
Is there any other experience from your first quarter or thoughts about being a transfer that you'd like to share?

# Appendix D

# Artifact: Equity and Inclusion in Physics Meeting Flyer

Figure D is an image of a flyer found in the hallways of the Main Building advertising meetings of the Equity and Inclusion in Physics group for undergraduate students. This flyer design was found vandalized in Main on two separate occasions.

# Undergraduate Equity and Inclusion in Physics



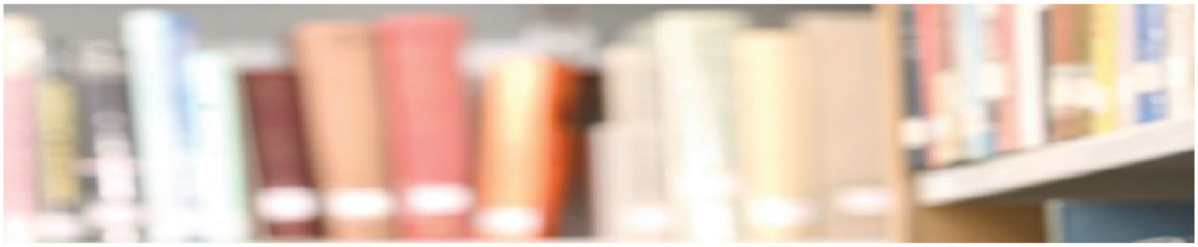
Tuesdays 4:30-5:30

Classroom 101

*We are a group of undergraduate students that are dedicated to attaining representation that reflects the American population with the goal of bettering the physics community.*

# Appendix E

# Artifact: Outreach Pamphlet



## Money in STEM

Science, Technology, Engineering, and Mathematics graduates with a B.S. have a median pay anywhere from $41K to $89K per year. Obtaining an advanced degree increases the median pay significantly. There are many jobs available with a B.S. or higher in STEM in industry and government; there are more jobs than just at a college. New jobs are frequently being added to the labor market, providing very stable employment.

## Dinero en CTIM

Graduados en Ciencia, Tecnología, Ingeniería, Y Matemática con un licenciado en Ciencias tienen un pago mediano de 41 mil hasta 89 mil por año. Obteniendo una licenciatura avanzado (Maestría y Doctorado). Hay muchos trabajos disponible con una licenciatura en industria y gobierno; hay mucho mas trabajos además de los que hay en una universidad. Nuevos trabajos son aumentados al mercado laboral, dando estabilidad en empleo.

## Community College

Community College is a great option for many students looking to get a four year degree. One can transfer to a university and save half the cost of attending. It also provides a low pressure environment where you can explore different subjects and see if it's a good fit. Many of the students at UC Davis are transfer students. Community college is a place to meet diverse people and gain confidence and a feeling of belonging.

## Colegio Comunitario

Colegio comunitario es una buena opción para estudiantes buscando a obtener un título. Uno se puede transferir a una universidad y guardar mitad del costo de atender. También proporciona un ambiente donde estudiantes pueden explorar diferentes sujetos y cer se es un buen ajuste. Muchos de los estudiantes en UC Davis son estudiantes transferidos. Colegio comunitario es un buen lugar para conocer gente diversa y obtener confianza y pertenencia en los files científicos.

## Low Income Resources

Between FAFSA, CalGrant, ChaFee, Cal Dream Act (applies to AB540/ DACA students), academic and non-academic scholarships, there is plenty of money available. But this doesn't answer the question of getting READY for college. Many free and subsidized tutoring programs exist. You can also check with your school district for academic after school programs.

## Recursos de Bajos Ingresos

Entre FAFSA, CalGrant, ChaFee, Cal Dream Act (para estudiantes de AB540/DACA), y becas académicas y privadas, hay mucho dinero disponible. Pero esto no responde la pregunta de cómo ponerse listo para el colegio. Existen una variedad de programas de tutoría que son gratis o subvencionado.También pueden chequear su distrito escolar para programas asistencia académica.

## Math Person Myth

**THERE ARE NO MATH PEOPLE**

Here's how to encourage a growth mindset instead of a fixed one:

1. Persevere through challenges.
2. Believe in your ability to overcome obstacles.
3. Embrace the words "yet" and "not yet."
4. Remember mistakes are normal.
5. Learn to see failures as opportunities to grow.

## Gente Matemática

**NO HAY GENTE MATEMÁTICA**

Esto es cómo alentar una mentalidad de crecimiento en vez de una mentalidad fija:

1.Persister a traves de retos.
2.Creer en tu habilidad de sobresalir enfrentando retos.
3.Abrace las palabras "aún" y "todavía no."
4.Recordar que errores son normales.
5.Aprender a ver retos como oportunidades de crecimiento.

## Stereotype Threat & Imposter Syndrome

Students of underrepresented groups often experience Stereotype Threat (poorer academic performance despite knowing the material) and Imposter Syndrome (the belief that their success is not deserved). Having conversations about this can combat these issues. If you or someone you know feels this way, increased awareness can help minimize these issues.

## Amenaza de Estereotipo y Sindrome del Impostor

Los estudiantes de grupos subrepresentados a menudo experimentan la Amenaza del Estereotipo (menor rendimiento académico a pesar de saber el material) y el Síndrome del Impostor (la creencia de que su éxito no se merece). Teniendo conversaciones de estos dilemmas ayuda a combatirlos. Si tu o alguien que tu conoces se sienten asi, conocimiento incrementado puede minimizar estos problemas.

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