Restructuring the Landscape of Learning Incentives in Higher Education: A Case for Process-Oriented Instruction and Assessment in Introductory Physics

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Abstract

This research considers the implications of introducing learner centered instruction and assessment through a *personalized learning* assessment scheme that included a group-project alternative to a standard multiple-choice midterm test in a large-scale, prerequisite freshman physics course for Life Sciences students. This process-oriented assessment style provided students with the opportunity to creatively apply course content to an area of their own interest by asking students to create concept-bridging questions in pairs that explored real-life applications of electricity and magnetism. A mixed methods explanatory sequential design approach was used to first survey a subset of the students (N=34), which was followed-up by an interview to select participants (N=8) about their experience in the course in order to better understand not only how students engaged with the course components, with particular emphasis on their choice of midterm assessment style, but also to address the nuance of how individual students chose to navigate a more flexible assessment scheme that created space for collaborative and exploratory learning. The results from this research indicate that providing students with the opportunity to creatively apply course content to an area of their own interest has the potential to stimulate a learner's desire to probe deeper into their understanding of the material and, possibly, to retain more of it in the process. Moreover, this research demonstrates that, even at scale, it is logistically feasible and pedagogically worthwhile to implement alternative methods of instruction and assessment to freshman-level students. However, despite attempts to introduce more student-centered learning into the course structure, our findings show marked resistance amongst members of this student demographic (over 50%) to engage with a high-stakes project-based assessment approach due to self-reported grade optimization concerns and general reticence to choose a grading scheme that presented them with greater uncertainty. The framing of this research further suggests that a shift towards active learning teaching strategies must be driven home by assessment schemes that encourage and reward process-oriented over outcome-oriented learning. This pedagogical realignment calls for an overhaul of the traditional assessment styles characteristic of most undergraduate science courses.

Keywords: project-based learning, inquiry-guided learning, curiosity-driven learning, constructive failure, active learning, physics education, process-driven learning, process-oriented instruction, process-oriented assessment, alternative assessment, large-scale courses, freshman physics, exploratory learning, collaborative learning, physics tutorials, learner agency, indeterminacy, self-directed learning

Résumé

Cette recherche examine les implications de l'introduction d'un enseignement et d'une évaluation centrés sur les étudiants, par le moyen d'un système d'évaluation de l'apprentissage personnalisé. Ce schéma comprenait un projet de groupe comme alternative à un test standard à choix multiples dans un cours de physique de première année à grande échelle pour les étudiants en sciences de la vie. Ce style d'évaluation axé sur le procès a donné aux étudiants la possibilité d'appliquer de manière créative le contenu du cours à un domaine qui les intéresse. Les étudiants ont été invités par paires à créer des questions qui tissent des liens conceptuels qui exploraient les applications réelles de l'électricité et du magnétisme. Une approche séquentielle explicative à méthodes mixtes a été utilisée pour sonder un sous-ensemble d'étudiants (N=34), suivi d'un entretien avec des participants sélectionnés (N=8) au sujet de leur expérience du cours. Notre objectif était de mieux comprendre comment les étudiants s'engageaient dans le cours, en mettant particulièrement l'accent sur leur choix du mode d'évaluation en mi-semestre. En outre, nous avons cherché à savoir comment les étudiants individuels ont choisi de naviguer dans un système d'évaluation plus flexible qui a créé un espace pour l'apprentissage collaboratif et exploratoire. Les résultats de cette recherche indiquent que le fait de donner aux étudiants la possibilité d'appliquer de manière créative le contenu du cours à un domaine qui les intéresse a le potentiel de stimuler leur désir a approfondir leur compréhension de la matière et, éventuellement, de mieux la mémoriser. En outre, cette recherche démontre que, même à grande échelle, il est logistiquement possible et pédagogiquement intéressant de mettre en œuvre des méthodes alternatives d'enseignement et d'évaluation pour les étudiants de première année. Cependant, malgré les tentatives d'introduire un apprentissage plus centré sur l'étudiant dans la structure du cours, nos résultats montrent une résistance marquée parmi les membres de ce groupe démographique d'étudiants (plus de 50 %) à s'engager dans une approche d'évaluation basée sur un projet à enjeux élevés, en raison de préoccupations déclarées d'optimisation des notes et d'une réticence générale à choisir un système de notation qui leur présente une plus grande incertitude. Le cadre de cette recherche suggère en outre qu'un changement vers des stratégies d'enseignement de l'apprentissage actif doit être renforcé par des systèmes d'évaluation qui

encouragent et récompensent l'apprentissage axé sur le processus plutôt que sur les résultats. Ce réalignement pédagogique nécessite une révision des styles d'évaluation traditionnels qui caractérisent la plupart des cours de sciences de premier cycle.

"Nine tenths of education is encouragement." (Anatole France)

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This is my love letter to the process of learning—the most honest reflection I could come up with to satisfy my unrelenting quest to reconcile the friction between chaos and structure, agency and prescription, freedom and constraint at the heart of the learning dialectic.

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> We tend to talk about education as a simple process of acquiring knowledge. On this view, education is about the transfer (or more accurately the copying) of information between the brains of teacher and learner. […] Learning, by contrast, changes the learner herself. We don't simply emerge from education with more things in our heads, but with different heads on our shoulders. We're given new habits of thought, and familiarized to new ways of seeing the world which force us to revise things we've believed without even noticing them. (Stokes, 2016, p. 94)

Chapter 1: Introduction

How do we judge a student's worth? Though the answer to this question may remain perennially rhetorical, the reality of its implications for a learner within the formal education system run deep. The rules of a game undeniably impact how a player will move within it. The same is also true within the context of higher education, where the constraints of a highly standardized educational system overwhelmingly privilege a strategic navigation mode that reinforces quantifiable grade-based achievement over the more qualitative and non-linear process of constructing knowledge through the cultivation of curiosity. (Kohn, 1999; Scouller, 1998; Shankar & Zurn, 2020)

Constraints matter. They serve to guide the direction of one's progression. Structure matters. Disciplinary knowledge requires a learner to be trained in accordance with a highly codified system. And yet, understanding how to follow rules is not sufficient to produce creative thinkers who can transcend them. (Davis, 1976; Tampio, 2019) Curiosity matters too and it is the secret ingredient that unleashes the creative mind. (Davidson & Katopodis, 2022; Shankar, 2020) Curiosity, however, is fickle and needs constant nurturing in order not to be stamped out once formal evaluation is introduced into the learning equation.

Despite significant innovation in teaching methodologies in university-level science education, grades remain the single most important marker of a student's demonstration of understanding; a sanctioned proxy for knowledge acquired. Grading is not inherently to blame but what is being graded needs to be considered at a more granular level in order to better chart a learner's progression. (Dixon-Roman, 2017; Schinske & Tanner, 2014)

Within Physics Education Research (PER) there is special consideration reserved for the teaching of freshman physics to Life Science majors, for whom introductory, large-scale prerequisite courses represent their last mandated exposure to the principles and methods of physics during their undergraduate degree. This research considers the implications of introducing learner centered instruction and assessment through a *personalized learning* assessment scheme that included a group-project alternative to a standard multiple-choice midterm test in a large-scale, prerequisite freshman physics course for Life Sciences students. This process-oriented assessment style provided students with the opportunity to creatively apply course content to an area of their own interest by asking students to create concept-bridging questions in pairs that explored real-life applications of electricity and magnetism.

A mixed methods explanatory sequential design approach was used to first survey a subset of the students (N=34), which was followed-up by an interview to select participants (N=8) about their experience in the course in order to better understand not only how students engaged with the course components, with particular emphasis on their choice of midterm assessment style, but also to address the nuance of how individual students chose to navigate a more flexible assessment scheme that created space for collaborative and exploratory learning (see Chapter 3). This study focuses on individual student experiences to try to understand the ways in which learning incentives are impacted once agency and choice are introduced into formal course assessment. It is not an attempt to quantify the unquantifiable impacts of this type of paradigm shift. Rather, this research seeks to shed light on the implications of qualitative assessment at scale for a highly grade-motivated student demographic—freshman students in the Life Sciences enrolled in a prerequisite course. By surveying and interviewing these students about their experiences, the aim has been to understand not only what is possible from an instructional design perspective but to address the nuance of how students navigate a more flexible course structure. More specifically, I sought to gain a better understanding of the implications of introducing the choice of collaborative and exploratory learning at scale to a highly risk-averse student demographic.

The results from this research indicate that providing students with the opportunity to creatively apply course content to an area of their own interest has the potential to stimulate a learner's desire to probe deeper into their understanding of the material and, possibly, to retain more of it in the process. Moreover, this research demonstrates that, even at scale, it is logistically feasible and pedagogically worthwhile to implement alternative methods of instruction and assessment to freshman-level students. However, despite attempts to introduce more student-centered learning into the course structure, our findings show marked resistance amongst members of this student demographic (over 50%) to engage with a high-stakes project-based assessment approach due to self-reported grade optimization concerns and general reticence to choose a grading scheme that presented them with greater uncertainty. The framing of this research further suggests that a shift towards active learning teaching strategies must be driven home by assessment schemes that encourage and reward process-oriented over outcome-oriented learning. This pedagogical realignment calls for an overhaul of the traditional assessment styles characteristic of most undergraduate science courses.

This research, therefore, functions at two layers of analysis. In its primary capacity, it serves as a means to examine the pedagogical and logistical limits of active learning at scale by investigating the implications of adapting an introductory physics course to satisfy the relational and exploratory learning needs of freshmen Life Sciences students through the creation of instructional and assessment approaches that promote collaborative learning and self-directed inquiry. At its core, however, this research rests upon one educational premise—the type of learner we are cultivating is determined by the way in which we score the learning process. Upon this axis, this research seeks to underscore and question the epistemological tension inherent to the institutionalization of learning by examining the effects of introducing open-ended inquiry into the purview of risk-averse students who have long been rewarded within a highly prescriptive educational system.

A Guide to the Research

This first chapter explains the purpose, objectives and rationale for this work and opens to a portrait of my personal experience in the formal education system. By providing insight into my own formative experience in higher education, I seek to invite the reader to consider how their own relationship with learning has been shaped, for better or for worse, by a system that often rewards grade-based achievement over the cultivation of curiosity.

The second chapter of this research lays the groundwork for the concepts that have guided my thinking, first, by explaining how this research understands the place and purpose of higher education and then by walking the reader through different pedagogical approaches and interventions that seek to instantiate these aims within the formal education system. The framing emphasizes the need for student-centered instruction and assessment in introductory physics by investigating how disciplinary epistemologies shape learner identity, the notion of self-directed learning and failure intolerance in academia, how social and project-based learning are linked to student motivation, and how there is a growing need for pedagogical innovation in the context introductory physics.

The third chapter provides an account of the research methodology that was used to frame the student feedback that was collected for the purposes of understanding the implications of introducing learner centered instruction and assessment through a *personalized learning* assessment scheme that included a group-project alternative to a standard multiple-choice midterm test in a large-scale, prerequisite freshman physics course for Life Sciences students. This chapter provides further context for where, how, and why this study took place. For the sake of methodological integrity, student-centered methods were employed to better understand the impacts of student-centered instruction and assessment.

The fourth chapter of this research presents and explores the findings and analysis of the aforementioned student feedback. By highlighting the core learnings from the student feedback survey (N = 34) and follow up interviews with eight students, this chapter seeks to demonstrate what is gained and what is lost from an assessment scheme that made space for collaborative and exploratory learning for this particular, risk-averse, student demographic.

The fifth chapter delves into the discussion of the salient findings. In particular, it focuses on what it means to shift the focus of assessment on the process rather than the product of learning. In the chapter I explain my own epistemological reframing of the purpose of this research as a means to evaluate the broader concept of assessment rather than one particular mode of assessment. With this shift in the lens of interpretation, this chapter makes the case for what it means to introduce process-oriented learning in the context of introductory physics.

The sixth and final chapter provides a summary of my core learnings and further explores the institutional impediments that resist systemic change, what this research has contributed to the field of physics education and where these questions could lead to further investigation down the line. The discussion of the implications of this research also includes a nod to the value of process-oriented instruction and assessment in an age of generative artificial intelligence. The chapter wraps up with a personal statement that serves as testament to the transformative impact of learning within the formal education system at the graduate level.

> "Why would you risk undergoing a process that might destroy the foundations of who you take yourself to be?" (Stokes, 2016, p. 94)

Insight Into the Research: My Heuristic Process

According to Strega and Brown, as researchers, we must recognize that the entirety of our perceptions and responses to our research are deeply rooted in ideologies that "frame our ethical and moral reasoning, our ways of knowing, thinking, being, and experiencing." (Stega & Brown, 2015, p. 8) In order to openly acknowledge these underlying ideologies from which we cannot divorce ourselves, the authors point out that we must disclose what drew us to our chosen research topic and all the choices we made and directions we took throughout the research process. An honest reflexive approach must, therefore, probe the nature of our relationships with study participants and provide insight into why we chose to omit certain aspects of the study or decisions not to pursue particular lines of investigation in our framing of the problem at hand. In order to satisfy this methodological transparency, there is a necessity for me, as the researcher in question, to disclose both my personal formal education journey as well as what I have come to understand as my philosophy of education—my heuristic learning process. The latter, I must admit, has been honed through my own fraught formative experiences in higher education. Revealing what I would characterize as my educational baggage, thus, serves as an attempt to shed light on patterns of thought that have shaped, both expanded and constrained, the scope of my inquiry.

In an effort to mitigate these inescapable biases, I have opted for a methodological approach espoused by Glesne and Peshkin who write that "rather than pursuing research with questions in search of the 'right' methods of data collection, I had a preferred method of data collection in search of the 'right' question**.**" (Glesne & Peshkin, 1992, p. 102) This search for the *right* question, the *right* lens through which to interpret my own personal experience within the education system, in combination with five years of my observations of the student experience in a freshman-level introductory physics course, was slow to ferment. Fermentation, in all its forms, takes time. And having the time and space to think is, in my opinion, the greatest affordance of higher education. As you will find reflected in this work, carving out space for *slow thought*, as coined by philosopher and psychiatrist, Vincenzo Di Nicola, has come to play an integral role in what I have identified as my philosophy of education and has greatly informed my framing of process-driven learning.

The beauty of slow, deliberate thought is that it creates space for what I now understand as the cornerstone of the learning process and a sorely undervalued feature in standard educational practices—*constructive failure*. The notion of constructive failure is the central artery that runs through my research. My grasp of its characteristics and parameters will be further expounded, but, as I seek to portray the reflexive nature of my investigation into higher education, I must draw attention to my personal relationship with failure as a student. Even as I extol its virtues, admitting to failure of any kind is a vulnerable experience. To have lived with failure in an educational context shapes an individual's perception of their identity as a learner, particularly when it comes to notions of intelligence. Standardized measures of intelligence, however, are not absolute—they are calibrated to detect only a fraction of highly contextually dependent variables. (Gee, 2001, p. 111; Tampio, 2019; Swinton, 2010) But what does it really mean to fail at learning and how does a fear of failure impact the learning process? In the words of Carl Wieman, renowned physicist and educational reformer, "[t]he place where learning happens is when you think about something incorrectly." (Weiman, 2022)

My own internalized perception of my abilities as a learner were irrevocably changed by one crucial experience that, to this day, delineates a marked shift in my relationship to formal education—dropping out of my undergraduate degree. My decision to leave was propelled by a seismic shift in my personal life but, in all honesty, I had been discontent with my university experience from the first day of classes. As an undergraduate student at a large-scale research university, my experience felt both intellectually underwhelming and overwhelmingly impersonal. Even as an engaged student, it was hard to not feel dejected as a result of trying to connect with overworked professors, with too little time to devote to their students, and apathetic peers, obviously more concerned with getting a degree than feeding their curiosity. And so, I left—half-way through my fourth semester, without any formal declaration of my intent to leave—in search of a more fertile learning environment. I could not appreciate, at the time, that I would carry the weight of this defiant act throughout the rest of my academic life and that it would only intensify both my desire to understand the internal machinations of the higher education system and my sensitivity to how it values its students.

Once you lose hope in your potential as a learner in the formal education system, it can seem almost impossible to muster the courage to stay the course. It ended up taking me five years but I returned to complete my undergraduate degree at the same university where I had started. Little did I know, however, that leaving my degree in the way that I did would open up a pandora's box of insecurity around my ability to succeed within an academic context. Confidence in learning is so often half the battle—confidence in your ability to start a problem and to work your way through it—just simply having the confidence to try. (Rust, 2002, p. 151) But confidence, like curiosity, is fickle and, in much the same way, it requires constant nurturing in order to not be stamped out once formal evaluation is introduced into the learning equation. As Wojecki (2007) so aptly describes, "[a]t the individual level, schooling can offer the confidence of becoming an educated, knowledgeable person. It can also saddle one for life with the feeling that one is doomed to fail. Schooling, in other words, is part of the complex process of shaping and reshaping the self.'" (Wojecki, 2007, p. 171)

Academia is not for the faint of heart. Developing learner resiliency is par for the course for any student intent on a college degree. Yet, some students navigate the higher education system with more weight on their shoulders. While there are students who go through university with a healthy dose of confidence, whether strengthened by successful past performances, a robust support network, or unassailable, eye-on-the-prize career goals, for others, every day is an uphill battle just to feel that they deserve a seat at the table. The lack of racial or socio-economic representation in academia, as just two examples, can take a toll on a student's ability and determination to stay within a challenging, bureaucratic system in which they already feel out of place. (Johnson, 2011; Seymour & Hewitt, 1997) These types of burdens in an academic context come to shape an individual's perspective of themselves as learners. (Wojecki, 2007) And yet, despite these wounding experiences, students can come to "narrate a different sense of identity" (Wojecki, 2007, p. 173) by being exposed to learning environments that ignite or reignite both their sense of curiosity in the world around them and the confidence they need in their ability to develop their own heuristic process of acquiring knowledge.

Over the years, I've noticed a spark in the eyes of many younger students I've spoken to when I tell them, as a current graduate student in the field of education, that I returned to school after dropping out. The mere knowledge that it was possible for someone to be granted a second chance within academia—that the rules were slightly more malleable than they appeared—

seemed to change the playing field for them. I recognize that being given a second chance is rare. Using that second chance to build and study new, more engaging learning opportunities for students within a rigid academic environment that had alienated me as a learner has strengthened my learner identity and my resolve to push the boundaries of what is possible within the formal education system. As much as this work has been for others, the reality is that it was fueled by my own private need to heal my relationship with my education. And, in the pursuit of this healing, I have nourished my endless curiosity in the process of learning.

Upon my return to complete my undergraduate degree, I found a few faculty members and students who, like me, wanted to make space for learning opportunities centered on the process rather than the product of learning. I was quickly brought into unconventional pedagogical projects like a Physics hackathon and an unconstrained research fellowship where both undergraduate and graduate students were given free rein to explore ideas of their own choosing and to define the parameters of their research. I learned, through this work, that what interested me was designing learning environments that had the potential to ignite a learner's curiosity. Freedom in the learning process, however, is a slippery slope. On one hand, the removal of constraints opens up endless possibilities to explore. On the other hand, the synthesis and application of what is explored requires a learner to be structured in their approach. It is one thing to remove constraints for students in informal, ungraded research projects, but the reality of translating this type of learning to meet the requirements of the formal education system is no trivial matter. (Davidson & Katopodis, 2022) This research seeks to understand how and whether curiosity-driven learning can be incorporated into a large-scale, graded course.

My work in physics education research came about somewhat haphazardly. More than anything, my involvement in this area of study was born out of a desire to support one professor's plan to flip a large-scale course, all on his own, without any dedicated institutional support. 'Flipping' a course is a term that refers to inverting the typical in-class/out-of-class breakdown of traditional instruction. Instruction—reading the course content and identifying where further clarification is needed—becomes the prerogative of each student before every class. Class-time is then reserved for dedicated problem-solving activities in which students are able to take full advantage of their teacher's support as they learn through active engagement. This description, however, is the best-case scenario and is typically only administered in upper-level courses that cater to experienced students with a math or engineering background. Flipping a class for 500+ life sciences students in their freshman year is an anomaly, one that I was eager to see in action. I, therefore, volunteered myself to act as an archivist-logistician-fly-on-the-wall—providing timing cues for in-class exercises, taking note of student participation, and rehashing my observations with the professor after every session. My role was informal, but it helped to keep the production afloat. The most valuable contribution I was able to make that first year was to survey students about their learning experience. Students were vocal in their interpretations of what worked, what didn't, and why, and that initial student feedback ended up feeding a five-year process of trying to fine-tune a course structure to provide this particular student demographic with the most appropriate and application-based version of what a large-scale freshman-level physics course could look like.

Central to the evolution of this work has been the involvement of students as partners in the process of designing, developing, and orchestrating a learning environment. (Healey et al., 2014) Active learning necessitates individual attention to student learning through small teacher-student ratios, all-too-often unfeasible given the logistical and financial constraints of large-scale introductory courses. This attempt to change the learning dynamic in a freshman course, therefore, necessitated a robust teaching team that could attend to the personalized needs of hundreds of students at a time. Throughout the five years of my involvement in this course, over 150 undergraduate students who had taken the course in a previous year returned to act as a peer mentors. Their roles varied from year to year, and, as the course structure shifted to better suit student needs, the role of the peer mentors grew. By the end, these mentors, many of whom played a recurring role from year to year, were tasked with leading small-group tutorials, a design component that has become the backbone of the course' structure. A few of these mentors have also gone on to participate in independent project-based courses that have helped to inform this research. By making space for students to take initiative, both for their own learning and for that of others, this course has inducted a large team of undergraduate students into the intricacies of pedagogical theory and practice, and strengthened a community of generous learners.

By honing in on individual student accounts, the following study delves into the ways in which agency and choice impact students' learning incentives once they are introduced into formal course assessment. It is not an attempt to quantify the unquantifiable impacts of this type of paradigm shift. Rather, this research seeks to shed light on the implications of qualitative assessment at scale for a highly grade-motivated student demographic—freshman students in the

Life Sciences enrolled in a prerequisite course. By surveying and interviewing these students about their experiences, the aim has been to understand not only what is possible from an instructional design perspective but to address the nuance of how students navigate a more flexible course structure. As a social scientist working within a Physics education context, my approach is not to prove a causal relationship between instruction and learning outcomes when there are too many confounding variables at play. Instead, my aim is to explore the multidimensional implications of introducing alternative assessment styles into the formal education curriculum in order to better understand what is at stake when the stochastic, non-linear exploration inherent to the cultivation of a learner's curiosity is incentivized within a standardized education context where students have been conditioned to prioritize grade-based achievement. (Swinton, 2010; Tampio, 2019) More than anything, my hope is that this research serves as both an encouraging portrayal of what is possible and a word of warning for anyone attempting a similar pedagogical endeavor.

In conclusion, this introductory chapter seeks to portray my personal lens into the research that follows. This effort in transparency allows you, the reader, to consider how your own experience may align or differ with the underlying premises that guide my reflection here on out. In the next chapter, I will build upon my epistemic lens to ground this research in the concepts and theories that have informed my investigation into the pedagogical interventions this research seeks to explore.

> We are loathe to give up the old. The old is bolstered by tradition, authority and respectability; and we ourselves are its product. If we view education, however, as the reconstruction of experience, does not this presume that the individual must do his own reconstructing? He must do it himself, through the reorganization of his deepest self, his values, his attitudes, his very person. What better method is there to engross the individual; to bring him, his ideas, his feelings into communication with others; to break down the barriers that create isolation in a world where for his own mental safety and health, man has to learn to be part of mankind? (Tenenbaum, 1959, p. 328)

Chapter 2: Conceptual Framework

A Return to First Principles: Exploring the Place and Purpose of Higher Education

Before diving into the particularities of the pedagogical context at hand, there is a need to set parameters for how this research sets up the notion of first principles in education. A return to first principles begs us to cast off assumptions and reconfigure our thinking around the fundamental dimensions of a given problem. The study of education requires an interdisciplinary investigation into everything from developmental psychology to social and economic systems, from cultural norms to the policies and politics that govern our legal framework. (Schinske & Tanner, 2014; Tampio, 2019) How, therefore, can we find consensus around the purpose of higher education? For this, I turn away from looking at education at the societal level and instead choose to scale my thinking to the level of the individual—what does it mean to be an educated person? One answer to this question that I have found particularly compelling comes from a talk given by the celebrated linguist and philosopher Noam Chomsky:

> It's not important what we cover in the class, it's important what you discover. To be truly educated from this point of view means to be in a position to inquire and create on the basis of the resources available to you which you've come to appreciate and comprehend. To know where to look, to know how to formulate serious questions. To question standard doctrine, if that's appropriate. To find your own way. To shape the questions that are worth pursuing and to develop the path to pursue them. That means knowing, understanding many things but also, much more important than what you've stored in your mind, to know where to look, how to look, how to question. How to challenge, how to proceed independently to deal with the challenges that the world presents to you and that you develop in the course of your self-education in inquiry, investigations in cooperation and solidarity with others.

> That's what an educational system should cultivate from kindergarten to graduate school and in the best cases sometimes does. And that leads to people who are, at least by my standards, well-educated. (2015)

Chomsky's perspective shares much in common with Paul H. Hirst's depiction of liberal education. According to Hirst, liberal education is "best understood in terms of the characteristics of mind to which it leads," which include "to think effectively, to communicate thought, to make relevant judgments, to discriminate among values." (Hirst, 1972, p. 79) This framing portrays the learned person not as one who has mastered discrete forms of knowledge but as one with mastery over the process of parsing, integrating, and presenting knowledge. Pedagogy, in accordance with this view, can be understood as a "relational, interreferential, and hermeneutic endeavour." (Donald, 2009, p. 5) To be learned, therefore, is to be a student of the process of learning—a never-ending transformation of the self. Hence, writes the philosopher of education, R. S. Peters, "[i]t is as absurd to ask what the aim of education is as it is to ask what the aim of morality is, if what is required is something extrinsic to education." (Peters,1965, p. 62)

Education, however, is also a form of socialization which cannot be disentangled from the processes of enculturation, whereby one is initiated into the norms and values of one's society. (Arendt, 1954; Charles et al., 2022; Dewey, 1916; Peters, 1965) Education, therefore, implies standards and not simply aims. It is this perpetual tug-of-war between the standards and aims of education that lies at the heart of my inquiry. Standards beget precision, which requires specialist training. Training entails the "acquisition of appropriate habits of response in a limited situation." (Peters, 1965, p. 67) But to be trained in accordance with disciplinary standards, however crucial, does not sufficiently capture the essence of learning—the unleashing of intellectual autonomy. (Bandura, 2006; Tampio, 2019) As such, an educational system that is transactional in nature will never be sufficient to unlock the processes of transformation that give rise to autonomous thought and action. (Davidson & Katopodis, 2022; Dewey, 1916; Schinske & Tanner, 2014; Tampio, 2019)

When considering this debate, it would be remiss to overlook the applied nature of educational scholarship. Research within the context of higher education is largely concerned with planning and measuring "interventions that will allow the system to function as it is *already* designed to do." (Dumas, 2018, pp. 30-31) The research at hand seeks to revisit this premise altogether through the lens of assessment. If the type of learner we are cultivating is determined by the way in which we score the learning process, then what do existing assessment practices tell us about the culture of learning that is being replicated in our universities? The implications of this question are non-trivial as, more often than not, assessment mechanisms "*produce* the personal characteristics they purport to measure." (Hanson, 1993, p.4)

Moreover, if, from a philosophical standpoint, the purview of the university is to support students to "navigate a complex array of learning experiences in which ontological and axiological transformation is as much at the forefront of learning as knowledge and skills," (Barradell et al., 2017, p. 270) then, how do the dominant pedagogical practices in prerequisite, large-scale university courses map on to this aspiration? To interrogate these discrepancies is by no means a novel approach to thinking through concerns in education. The work of political philosopher, Hannah Arendt, for instance, drew attention to the double bind of progressive and egalitarian socio-political forces at play in the American educational landscape, a bind as relevant today as when it was first written in the 1950s. (Arendt, 1954) And yet, there is still value in highlighting and exploring the tensions that continue to exist between the aims and realities of educational practices. This work, therefore, is an exercise in holding and acknowledging these tensions rather than overlooking or simplifying them, because, these tensions, however aggravating, are also inescapable. (Donald, 2009, p. 534) It is only by first recognizing the complexity of the educational problems at hand that we can attempt to, not *resolve*, but address the characteristics of thought that continue to uphold Crotty's so-called "tyranny of the familiar". (Crotty, 1998, p. 59)

A Turn Towards Student-Centered Instruction

According to Dewey, one of the most foundational figures in modern political and educational philosophy, "it is illiberal and immoral to train children to work not freely and intelligently but for the sake of the work earned, in which case their activity is not free because not freely participated in." (Dewey, 1916) Central to Dewey's perspective on progressive pedagogy is the recognition that all learners enter the classroom with their own pre-existing ideas and interests. By highlighting the cognizance of the student, Dewey promotes a view of education that centers around tapping into a learner's inherent desire to understand the world around them. As such, instruction within the formal education system is a means to harness the student's ability to exercise their own heuristic approach to the process of learning. (Tampio, 2019, p. 79) Although Dewey's influence on the social conscience of the Western educational landscape remains far-reaching to this day, modern educational practices, which have undergone countless societal reforms over the last hundred years, have deviated significantly from this lofty pursuit. And yet, more recently, a return to student-centered instruction has been on the rise. But what is student-centered instruction and how does it align with Dewey's pedagogical perspective?

Current trends in pedagogical innovation research tend to lionize evidence-based instructional practices. This approach to the study of education has opened the door to a reevaluation of the classroom conditions that have been shown to increase student performance through the use of active learning teaching techniques. As a result, this shift has repositioned the student, rather than the teacher, at the center of the learning equation through student-centered instruction. Student-centered instruction is a broad term used to describe pedagogical approaches based around the idea that student learning is improved by giving students more opportunities to engage actively with their own learning. Oftentimes, the implementation of this approach reallocates class time that had previously been reserved for teacher-centered instructional methods, such as lectures, to be substituted for student-centered active learning methods that encourage students to learn more independently from their instructor. (Felder & Brent, 1996, p. 43) Students may, for instance, be asked to come to class having first read the assigned content on their own, rather than relying solely on their instructor's way of framing the course material. Other examples of student-centered instruction may encourage students to explore open-ended problems that require more complex thinking and problem-solving abilities. Oftentimes, there is an added emphasis on students being expected to engage with their peers as a means for cooperative, relational learning.

The goal of student-centered instruction is, in many ways, an instantiation of Dewey's desire to create a learning environment that might cater to the student's own curiosity while also allowing for the cultivation of their "natural interest in the flourishing of others." (Tampio, 2019, p. 79) This reframing has brought about a shift from "focusing on teaching to focusing on learning" (Whetten, 2007, p. 343) through the notion of learning-centered course design. According to much of the research on learning-centered course design, when implemented carefully, these pedagogical approaches are shown to increase both a student's motivation towards learning and their ability to retain and apply the course content. (Felder & Brent, 1996) This emphasis on designing a learning environment around the ways in which a student is meant to be navigating their learning has shaped the structure of many university-level courses. And yet, despite these pedagogical developments, there is still a significant lag between changes to the ways in which students are being taught and changes to the ways their learning is being assessed. (Rust, 2002, p. 146)

As Gibbs points out, like it or not, "assessment systems dominate what students are oriented towards in their learning." (1992, p.10) The implications of this statement signify that it is paramount to align both instruction and assessment as the two pillars of the learning process. Thus, even if students are being instructed according to student-centered active learning strategies, the reality of how this type of learning is being measured will define how students navigate their learning in a given course. It is assessment and not instruction that grounds the learning process because it is through assessment that value is placed on the learning achieved. (Brown, 2005, p. 82) Students, therefore, need to be evaluated in manners that push them beyond a simple recall to memorization and regurgitation. (Rust, 2002, p. 147) However, the reality, according to Rust, is that many university classes continue to assess students in accordance with traditional modes of instruction that do not sufficiently assign weight to the skills that are developed through student-centered instruction. (Angelo, 1996, p. 3) Accordingly, as long as students can get by without being asked to demonstrate deeper approaches to their engagement with the learning process, they have little incentive to change their learning habits. (Rust, 2002, p. 149) With this awareness, we must devote more attention to the role of course design in facilitating student-centered instruction and assessment.

According to Gibbs (1992), the characteristics of a course that can be associated with more surface-level learning are (1) a heavy workload, (2) relatively high class contact hours, (3) an excessive amount of course material, (4) a lack of opportunity to pursue subjects in depth, (5) a lack of choice over subjects and a lack of choice over the method of study, and (6) threatening and anxiety provoking assessment system. (p. 9) On the contrary, course characteristics that have the potential to foster a deeper approach to students engaging with their learning are: (1) the engendering of intrinsic motivation in the students; students wanting and needing to know, (2) learner activity, (3) interaction with others, and (4) a well-structured knowledge base – i.e. where content is taught in integrated wholes and where knowledge is required to be related to other knowledge. (pp. 10–11) Although these changes may appear straight-forward, their effect on how students perceive their learning is a different story. In fact, it should be noted that faculty members who implement these types of changes in their courses need to be aware of many misconceptions when it comes to how students view student-centered instruction. (Felder & Brent, 1996) Despite the foretold benefits, Felder and Brent explain that the observable advantages of adopting student-centered instructional methods are “neither immediate nor automatic.” (p. 43) This is partly because students who have grown accustomed to traditional modes of instruction often feel that the rug has been pulled out from under them when their familiar teaching tactics and tools are taken away. The effects of these changes to the learning environment take time and effort for both students and faculty to regain their footing. Felder and Brent warn of their own experiences with hostile student push-back as a result of instructional methods that required students to take more responsibility for their own learning. Common student complaints, according to the researchers, included the accusation that instructors were reneging on their teacherly responsibilities to ‘teach’ or that being forced to work in teams was a waste of time. The authors note that adopters may also see their course ratings drop as a response to these changes as students' perceptions of their learning undergo a shift.

The gap between students’ ‘actual learning’ versus ‘feeling of learning’ in response to student-centered instructional practices was investigated further by Deslauriers et al. By comparing students’ self-reported perceptions of learning against their demonstrable improvements in understanding under controlled conditions in large-scale introductory college physics courses, the researchers argue that attempts to evaluate instruction based on students’ perceptions of learning could inadvertently promote inferior (passive) pedagogical methods. This is because, after evaluation, it was shown that the students who were randomly placed in active classrooms outperformed their peers from more passive classrooms even though their self-reported perception of learning had taken a hit. However, the study’s findings also show that the “increased cognitive effort associated with active learning” (2019, p. 1), can have a negative impact on the motivation and self-regulation of unreceptive students. The power of perception is such that this initial discomfort may indeed impair students’ desire to engage with and, therefore, *learn*, the course content. And yet, Felder and Brent assure practitioners that it would be a mistake to give up when faced with these initial struggles. Although there are steep learning curves involved, both for students and their instructors, the ultimate impact of student-centered instruction is undeniably beneficial to student learning. (p. 43) That said, significant reshaping of student incentives is needed to encourage reluctant students to shift their behavioral patterns away from what has worked for them in the past.

Disciplinary Epistemologies and the Shaping of Learner Identity

In building learning environments around the student, it becomes crucial to recognize the weight that "personal knowledge and affect—values, assumptions, biases, dispositions and motivations" (Barradell, et al., 2017, p. 271) have on a student's ability to engage with their learning. Through exposure to distinct disciplinary perspectives in their first years of university, students begin to familiarize themselves with the "language, tools, norms, and standards of a discipline." (Charles, 2022) As they build ties to specific communities of thought, students can learn to appreciate the ways in which formalized knowledge is constructed, normed, and disseminated, and, in doing so, build their own arsenal of skills and abilities that will help them engage further in the "process of knowledge production." (Barradell, et al., 2017, p. 270)

These epistemological differences in how knowledge is constructed and applied across disciplines provide valuable insight into the contrasting pedagogical norms and practices across academic contexts. As an example, Meredith and Redish highlight the impact that distinct disciplinary epistemologies have on curricular choices between physicists and biologists. According to the authors, physicists have a tendency to "build understanding from simple systems that are amenable to quantitative analysis." (2013, p. 40) This approach to thought necessitates an abstraction of the variables in a given situation in order to focus on and derive meaning from the most fundamental dynamics at play. Biologists, on the other hand, approach observations of the natural world from a standpoint that takes for granted that "everything takes place in a fluid environment—air or water—and [that] the fluid has a critical influence on biological function." (p. 40) This distinction shapes how physicists and biologists employ notions of complexity and abstraction in the processes they use to distinguish between 'correct' and 'non-correct' answers.

Moreover, these disciplinary 'ways of knowing' are further reinforced in university-level courses by discipline-specific modes of instruction and assessment that come to shape how a student perceives themself as a learner. This phenomenon can be observed through traits that particular student demographics adopt in response to specific disciplinary exposure. For instance, the authors note that life sciences students (i.e., students enrolled in biology, anatomy, physiology, neuroscience, etc.) tend to be less adept at using mathematical thinking than their engineering or physics peers, and, for this reason, rely more heavily on ‘plugging and chugging’ equations rather than trying to understand their base components. Physics, therefore, “provides an ideal context in which students can learn to synergistically blend quantitative analysis and modeling with the sensemaking skills they will need in their advanced biology courses and careers.” (Meredith & Redish, 2013, p. 41) The interplay of these epistemological perspectives has the potential to provide life sciences students with greater insight into the physical laws that govern all life on earth. With this in mind, the pedagogical challenge of teaching a prerequisite physics course to life sciences students is made only that much more apparent.

Beyond exposure to disciplinary epistemologies, there are other, more covert, ways in which a student’s learner identity is shaped by the educational system. Wojecki highlights the need to address the consequences of "didactic and reductionist” (2007, p. 170) pedagogical praxis, which, according to the author, has the potential to engender “wounded learners,” described as students whose ability to engage in the learning process has been compromised by a “standard paradigm of learning,” characteristic of much of formal education, that emphasizes conformity through highly standardized evaluative practices. (p. 170) The role that evaluation plays in perpetuating these damaging side effects should not be underestimated. And yet, Wojecki points out that students’ relationship to learning is more plastic than we might expect. Exposure to “[n]ew, more engaging experiences with learning” (p. 173) can allow a student to redefine their relationship with the learning process. Moreover, nurturing a learner’s curiosity by encouraging them to build their own lines of inquiry and to consider the boundaries of their disciplines can provide students with a chance to consider how they may, in turn, be able to contribute to the existing body of knowledge. (Shankar & Zurn, 2020) And thus, re-centering the educational process around a student’s learner-identity needs has the power to transform formal education into a motivating and healing pedagogical practice. (Davidson & Katopodis, 2022)

Self-Directed Learning and the Culture of Failure Intolerance in Academia

Curiosity, write Shankar and Zurn (2020), is a “type of knowledge-emotion” (p. 109) that is deeply “environmentally interconnected, socially embedded, and politically dynamic.” (p. 276) Within the context of higher education, a student’s natural capacity for curiosity has the potential to be enhanced in ways that expand the learner's framing of what is possible. On the flip side, an individual's inherent sense of curiosity can also be fashioned in accordance with restrictive mechanisms that "reinforce established patterns of thought, including those that subtend social inequalities." (p. 276) In essence, however, curiosity can be understood, not as a fixed trait, but as a "constantly shifting relation between the knowledge one acquires and how one feels about the knowledge one acquires." (p. 109) Moreover, as an emotionally-dependent mechanism through which a learner approaches the process of intellectual exploration and knowledge construction, curiosity is woven into complex social, political, and economic "regimes of value" (Foucault, as cited in Shankar & Zurn, 2020, p.110) that serve to guide and orient the ways in which it manifests. As a result of its contextually-dependent nature, an individual's ability to manifest curiosity can either intensify or wane based on various internally- and externally-derived factors, such as interpersonal accountability and desired applications of knowledge.

Within the context of formal education, Shankar and Zurn (2020) argue that the cultivation of curiosity has largely been tapered to fit its role as currency for "economic mobility and drive." (p. 108) This commodification of the learning process sets limits on the types of knowledge the learner chooses to pay attention to and, importantly, what they do not. (p. 109) Curiosity, therefore, falls prey to many of the same forces as other forms of cultural reproduction. (p. 110) Indeed, this notion of 'what one ought to know' is very much at play in the context of any prerequisite freshman-level course. This type of learning environment is ripe with students whose attitude toward learning has already been shaped by pre-determined notions of success and failure in regards to educational achievement. These perceptions of self-worth and intellectual ability are often forged in relation to their test-based performance. But performing well on a test, particularly when it comes to standardized evaluation, does not convey the full breadth of a student's understanding or potential. What's more, by narrowing in on only particular aspects of a student's test-taking abilities, experience in the educational system can have the effect of exposing students to heightened levels of stress and anxiety—feelings that can be hard to disentangle from the learning process. (Shankar & Zurn, 2020, p. 111)

In this portrayal of the education experience, it is worthwhile to point out that the notion of what a student is curious about is rarely assigned importance to in formal curricula. As such, students are often forced to reconcile between the competing pulls of what they 'want to know' versus what they 'ought to know' as they navigate their education. However, in trying to better understand the unintended consequences of introducing choice into the learning equation, it is also important to note that more choice does not automatically lead to more freedom for most students. In fact, when given curricular leeway, Shankar reports that strategically-minded students will often choose to optimize for grading schemes they deem either more familiar or more lenient, a trend that must be taken into account in the designing of student-centered learning environments. (Shankar, 2020) Although these patterns of risk-averse behavior amongst many student demographics are public knowledge, there is a dearth of research that explores the long-term consequences of outcome-based, risk-averse learner behavior both within and beyond the formal education system. (Kohn, 1999) The research outlined in this study seeks to address these gaps in understanding by allowing students enrolled in a large-scale prerequisite course to choose their preferred assessment approach through a *personalized learning* assessment scheme (see Chapter 3).

Shankar has sought to address the "risk-security paradox" (2020, p. 117) that underscores much of the learning process in higher education. By not taking risks, he explains, "students fail to develop the very skills during college that would make them feel more secure with the uncertainties that are inevitable during life in and after college." (p. 118) Chief among these skills, according to Barradell et al. (2017), is the ability of students to entertain and work through the notion of uncertainty. But dealing with uncertainty, write Barradell et al., "requires that students have certain dispositions to knowledge and learning." (p. 272) These dispositions, according to Peters (1965), can only be cultivated by "letting individuals choose for themselves, learn by experience, and direct their own lives," (p. 64) a pedagogical approach that redirects the learner's attention away from an "illusory 'end'," (p. 64) and towards a methodology of learning. Shankar echoes this framing, attributing much of modern-day risk-aversion amongst college students to what the author calls a neoliberal educational system that places the emphasis of value on the final product of learning rather than the process that was needed to get there. And, as a result, this system perpetuates schools, described by acclaimed writer and social commentator, Ta-Nehisi Coates, as "not concerned with curiosity, but [with] compliance." (Coates, 2015, as cited in Shankar & Zurn, 2020, p. 270)

But what, according to the authors, is responsible for this risk aversion that has become so characteristic of today's educational system? Educational researcher, Peter Moran (2015), who has studied the risk-averse nature of contemporary American public education, points to policies that have sought to "bring uniformity and predictability to public education," (p. 261) such as standardized testing as a root of this widespread behavior. Shankar and Zurn (2020) further explain that standardized testing, in which students are conditioned to restrict their questioning only to that which can be answered, has played a key role in creating a pedagogical culture in which students are afraid of asking the wrong question or of "asking a question that will reveal their lack of knowledge." (p. 278) It is the fear of failure that reinforces negative emotions in connection to the concept of uncertainty. But, as the authors point out, cultivating a sense of inquiry in a student goes hand in hand with familiarizing a learner with the "experience of not knowing." (p. 278) an essential component of exploratory learning. By encouraging students to 'fail forwards' (Peschl et al., 2020, p. 2) learning environments can support the long term retention and transfer of knowledge rather than simply test-based performance, which correspond to little more than "the temporary fluctuations in behavior or knowledge that can be observed and measured during or immediately after the acquisition process". (Soderstrom & Bjork, 2015, p. 176) This is because, on the path towards problem solving, the knowledge of *why* something does not work is much more fruitful than the knowledge *that* it does not work. It is only through the process of trial and error that a learner can discover "why the 'stupid' errors are 'stupid.'" (Davis, 1976, pp. 63-64)

What, therefore, would it take to unleash a learner's curiosity in the formal education system? In developing a stimulating and meaningful learning environment, there is insight that can be taken from looking at pedagogical approaches that have been developed for design-specific education. According to design pedagogy, learning experiences should develop natural motivations to create a resilient, informed, and sustainable capacity to learn. This approach to the learning process suggests that students need the time, space, and structure to immerse themselves in a context that supports the concept of uncertainty such that they can hone skillsets that are better suited to navigate disruptions and challenges with ease. (Tovey, 2015) Embracing failure is seen as necessary to sustaining students' personal motivation and their ability to effectively self-manage. As an active process, learning requires application and practice. Exposing students as much as possible to challenging exercises allows them to build upon their existing knowledge and develop their own heuristic learning process. (Davis, 1976; Stigendal & Novy, 2018) Only through strengthening a student's desire and ability to navigate through uncertainty can our educational structure produce thinkers who can engage critically with their environments when faced with “differences, unknowns, or uncertainties.” (Shankar & Zurn, 2020, p. 278)

How Social and Project-Based Learning Are Linked to Student Motivation

“Nothing,” write David and Katopodis, “about our systems of education nor our ideas of research exists in a vacuum.” (2022, p. 170) Naturally, therefore, students respond positively to being able to situate and apply their coursework within a real world context, thereby reframing their pursuit of knowledge as a means to understand how something works rather than, simply, how to get a point. Project-based learning allows students to engage with a deeper level of conceptual understanding by probing their ability to “acquire and apply information, concepts, and principles,” (Blumenfeld et al., 1991, p. 373) which also has the potential to improve a student’s metacognitive abilities to track and evaluate their own learning and that of their peers. (Davidson & Katopodis, 2022)

Let us consider student-centered instruction in the context of a large-scale prerequisite physics course for life sciences students. In addition to the mandatory nature of this type of introductory course, there are additional factors that have the potential to undermine the motivation of the student demographic in question. For instance, many students enrolled in a Life Sciences program are hoping to pursue careers in the medical fields, and therefore face tremendous pressure to maintain top grades throughout their degree. (Kortemeyer, 2007) This extrinsic pressure often impacts the manner in which a student chooses to navigate both the courses they elect to take as well as the modes of instruction they opt into when given a flexible grading scheme. Strict grade constraints, therefore, have the potential to compromise a learner’s intrinsic motivation to engage with course material. (Ryan & Deci, 2009, p. 174) As a remedial pedagogical tactic, intrinsic learner motivation can be nurtured through fostering learning communities that reinforce learner accountability and deliberate practice. Part of the aim of this research, therefore, is to design learning structures that emphasize practice, discussion, and constructive failure while allowing for a mode of assessment that privileges process, iteration, and collaboration. This approach serves to keep students accountable for their learning through regular access to a discursive learning structure that offers participation points for active student engagement. Having made this claim in favor of collaboration, the question, which this research seeks to address, is how to implement relational learning into the structure of a large-scale course of more than 500 students.

The understanding of learning as rooted in a process of reciprocal exchange stems from *social development theory*. In direct contrast to traditional ‘transmissionist’ models of instruction, in which learning is perceived as the uni-directional passing of knowledge from an active instructor to passive students, this theory assumes the need for students to play an active role in their learning. This framework suggests a reconfiguring of knowledge transfer as an active exchange between alternating passive and active members as personified by an instructor and their students. As a result, learning, or the construction of meaning, takes the form of a reciprocal exchange. Social Development Theory places emphasis on learning as occurring through the combination of students actively performing set tasks under three separate conditions: (1) under the professor’s guidance, (2) in collaboration with peers, and (3) autonomously. (Vygotsky, 1962) These three fundamental modes of knowledge development are taken into account by providing students with a more or less equally weighted combination of instructor-led and mentor-facilitated classroom exercises with smaller scale tutorial peer-learning environments and required independent homework. These three distinct modes of learning, thus, reinforce one another and allow students to solidify and build a solid base of content understanding through active problem-solving. Collaborative learning environments further serve to encourage social accountability in the learning process while simultaneously breaking down the anonymity faced by students in large-scale freshman courses.

With the aim of addressing motivational issues amongst freshman life sciences students enrolled in a large-scale prerequisite physics course, there is further need to consider pedagogical approaches that encourage ownership of the learning process through self-direction and choice. Providing students with the opportunity to creatively apply course content to an area of their own interest has the potential to stimulate a learner’s desire to probe deeper into their understanding of the material and, possibly, to retain more of it in the process. (Ryan & Deci, 2009) The cultivation of curiosity motivates a learner’s desire to explore, which, in turn, sets in motion the self-reinforcing processes of concept integration and reformulation inherent to learning. Physicist and educational researcher, Natasha Holmes (2013), underscores the necessity of *high agency* for inventive thinking, which is characterized by a combination of autonomy and limited externally imposed scaffolding. Central to this depiction of agency is the element of choice. (Haynes et al.,

2009) When students are provided with a sense of choice, "volition, self-determination and responsibility" (Nilson, 2016) ensue. In contrast, the absences of these conditions in an overly prescribed and curated learning environment can have the effect of undermining a leaner's inquisitiveness, thus reinforcing feelings of apathy and passivity in the learner. (Haynes et al., 2009) When the driving ethos becomes: 'what are you curious about?' rather than 'apply what you were told in class,' the rules of the game are turned on their head.

One of the central theories in human developmental psychology to consider in this context, motivation theory, is tied to Maslow's broader *hierarchy of needs* that, if fulfilled, have the potential to unleash innate human curiosity. After basic physiological and safety needs are met, Maslow suggests that individuals have fundamental psychological and self-fulfillment needs that require nurturing in pursuit of a broader sense of achievement and satisfaction. (Maslow, 1943) An interpretation of motivation theory places importance on the role of self-actualization and self-governance in the learning context for freshman students, thereby encouraging self-initiation. (Ryan & Deci, 2009, p. 174) Through understanding the role that motivation plays in a student's ability to focus and learn new material, it becomes possible to create learning structures that foment a sense of determination among students. In this way, heightened motivation and determination can be seen as the product of structural changes to incorporate a personalized learning approach in combination with access to a project-based learning environment. (Ames, 1992)

Another key theory at the heart of relational pedagogical approaches is self-determination theory, which suggests that learners are able to acquire agency and self-determination when their needs for three main criteria are met—competence, connection, and autonomy. *Competence* refers to the mastery of tasks and learned skills. When a person feels that they are equipped with the skills needed for them to succeed at a task, they are more likely to be intrinsically motivated to take actions that will help them to set new and more challenging goals. *Connection* implies that a person needs to experience a sense of belonging and attachment to others in order to feed their sense of intrinsic motivation. *Autonomy* signifies that a person needs to feel a sense of control of their own behaviors and goals. The ability to have the freedom of choice and opportunity to take action of their situation and live out the consequences of their choices plays a significant role in helping them to feel self-determined and motivated to play an active role in their own lives. (Wentzel, 2009, p. 303) Self-determination theory operates under two main assumptions: (1) each individual's needs for growth are the driving forces behind their behavior, (2) motivation that is autonomous and self-guided is crucial to development. Therefore, according to this theory, people are rational agents that gravitate towards the need to grow and develop, which is understood as gaining mastery over challenges and being presented with new experiences. Although learners are often motivated to act through external motivating factors, in this case, grades, self-determination theory places utmost importance on internal sources of motivation such as the need to gain knowledge or independence (intrinsic vs. extrinsic motivation.) (Ryan & Lynch, 2003) Accordingly, providing students with a sense of control through the means of choice can serve to increase their intrinsic motivation to learn. (Haynes et al., 2009, p. 238) In the context of an introductory physics course, traditional grading approaches offer little leeway for students to take initiative for their own learning when assessment schemes often follow pre-set problems for students to solve. The introduction of a group project in the context of this study provides an instantiated example of the impacts of the aforementioned learning mechanisms at the heart of self-determination theory for the student demographic in question.

Under the umbrella of relational learning, the theory of situated learning proposes that the process of learning should be considered as it relates to the context and culture in which it occurs. (Lave & Wenger, 1991) According to this theory, students should be presented with the contextual relevance of the content at hand in order to give the course material applied meaning. Considering that learning can be understood as the act of building upon a framework of bridged knowledge-nodes, this learning theory suggests that students will be able to absorb content more readily and profoundly if it is explained with contextual relevance. Take for example the difference between explaining an abstract physics concept such as electric charge to freshman Life Sciences students versus relating this concept to neural pathways. By incorporating the curricular concept into real-life applications that may seem particularly relevant to their interests, the concept is brought to life. This theory further underscores the importance of social interaction in the process of situated learning. Learners are understood as active members in a 'community of practice' which strengthens and deepens the bonds of thought production and idea exchange. (Wenger, 1998) This community of learners helps to reinforce the act of knowledge production and serves as a way to keep students accountable to develop and broaden their existing knowledge. Part of the success of these communities of practice lies in the fact that they are peer-to-peer exchanges that include more experienced and less experienced members. (Salomon & Perkins, 1998) According to this theory, situated learning emerges from what are often non-deliberate exchanges, there is thus an element of spontaneity to the learning process that should be taken into account. (Brown et al., 1989) This conceptual framing further underscores the need for small-scale tutorial-style learning communities within the context of a large-scale, highly anonymous introductory course.

Restructuring a class environment to align with these theoretical principles and ideas requires instruction and assessment to deviate from focusing on the memorization of terms and procedures towards the creation of novel, unprescribed approaches to the complex problem-solving of concepts that are rooted in real-world practice. (Turner & Patrick, 2008) The theory of situated learning, in particular, which is a forerunner of many active learning teaching methods, can have a galvanizing effect on learner-motivation. However, the concept of a 'community of practice' is pushed to its limits within the context of a 500+-student introductory course. The research at hand seeks to adapt this notion of *situated learning* when incorporating active learning teaching methods into the structure of a large-scale introductory course and, in doing so, highlight the ways in which scale can obfuscate many of the intended theoretical benefits. Through the introduction of tutorial learning environments and a group project that asked students to build concept-bridging questions in pairs, this study context allows me to investigate what elements of situated learning can be encouraged in a large-scale introductory course (see Chapter 3). In keeping with this approach, the complexifying issue of scale should not be overlooked in education research as a defining feature of the pedagogical culture of many institutions of higher education today. Thus, this understanding of social exchange as foundational for meaningful applied learning serves as an argument in favor of smaller-scale, peer-to-peer learning environments.

The Growing Need for Pedagogical Innovation in Introductory Physics Education

Despite the growing body of evidence in favor of pedagogical approaches that promote active and inquiry-guided learning through research-based methods, traditional, lecture-based instruction is still ubiquitous in large-scale introductory physics courses. (Wieman, 2017) The resolution of physics problems necessitates the conceptual understanding of the underlying physics principles at play. Research into physics education over the last decades indicates that many students “retain fundamental conceptual difficulties, even after instruction.” (Kima & Pak, 2002, p. 759) Wieman explains this by saying that:

> Most students are learning that “science” is a set of facts and procedures that are unrelated to the workings of the world and are simply to be memorized without understanding, and they learn to “solve” science problems by memorizing recipes that are of little use other than passing classroom exams. (Wieman, 2017, p. 6)

Wieman’s observations point out the need to reorient the ways in which undergraduate students are introduced to physics concepts such that they can better understand and appreciate the interconnected and experimentally determined nature of scientific understanding. In order to cultivate these expert-like attitudes towards the practice of science, students need to be exposed to concept-based problem-solving methods that stimulate open-ended inquiry. (Wieman, 2017, p. 6)

In order to anchor my own work within the broader landscpe of pedagogical experimentation and innovation in physics education, Weiman’s thinking has led me to other educational researchers pushing the boundaries of what is possible in introductory physics. Among them, the work of Meredith and Bolker (2012) from the University of New Hampshire stands out as a research approach to instructional design that is particularly aligned with the epistemological interests and logistical constraints at play in the context of my own research. In an attempt to adapt a large-scale freshman physics course for students enrolled in the Life Sciences, Meredith, a physicist, and Bolker, a biologist, co-developed and co-taught an interdisciplinary introductory physics course that ranged in size from 250-320 students and collected data to further ascertain whether their instructional approach reinforced students’ abilities to integrate the two disciplines. The lecturers and researchers viewed their interdisciplinary approach as not only pedagogically beneficial to their students but also as a means to model collaboration that “sends a powerful message about the value [they] place on integration.” (p. 914) Similar to my work, their approach went beyond the simple injection of biology content into a physics course but rather transformed the course structure in order to privilege “authentic scientific inquiry in the classroom” (p. 914) through the use of peer instruction, group problem solving on challenging questions, and encouraging students to refine their disciplinary intuitions. One important insight that emerged in their deliberate effort to identify course content that would be relevant to their student demographic was the need to omit certain topics that had traditionally been understood as core curricular content for a course at this level. (p. 915) The authors recognize that this culling issue presents significant challenges at the interpersonal and institutional levels as there is often a lack of consensus over curricular mainstays between individual faculty members, let alone across entire departments. Their research shows that building a physics course designed for Life Sciences students, therefore, presents the need for interdisciplinary negotiation and faculty-wide agreement. (p. 920)

In a similar vein, according to physics education researcher Natasha Holmes (2015), the teaching of quantitative critical thinking, by which she means the ability to conceptually interpret complex quantitative information, is a "fundamental goal of science education" that is "seldom, if ever, being achieved." (p.1) In order to address this pedagogical concern, the author developed a method of instructional design based on an analysis of the cognitive processes responsible for critical analysis. Central to Holmes' approach to helping students hone their skills in critical thinking is the idea that students need to be given the opportunity to practice making their own decisions based on data and to receive feedback on their decision-making process. This learning methodology, in line with inquiry-based modes of instruction, was developed within the context of an introductory physics laboratory course. Holmes' work is in direct reference to that of Buck et al. (2008) who have sought to design a rubric structure to standardize instructional practices that take into account the "cognitive and epistemological components of inquiry." (p. 53) The goal of inquiry-guided learning is to decrease the amount of instructional scaffolding in a learning environment such that students can, gradually, come to a level of independence in their framing and reasoning, thereby developing their intuitions for authentic, open-ended inquiry. (p. 54) This notion of authentic inquiry is understood as the final level of intellectual autonomy in a formal education context in which students are asked to come up with a problem worth investigating and tasked with setting and working through their own definition of the parameters needed to resolve it.

Holmes (2015) proposes that the reason that many students do not exhibit these behaviors is due to a lack of exposure to inquiry-guided learning in the formal education system. Showing students how experts in a given discipline engage with complexity is not sufficient, students require explicit and repeated practice of their own with open-ended inquiry in order to develop an intellectual framework that supports critical thinking. In this process of familiarizing students with exploratory learning, constructive and targeted feedback provides a crucial mechanism for students to hone their interpretive lens. In doing this, Holmes emphasizes that students benefit from instructors being explicit about the ways in which employing a critical thinking process allows students to make their own discoveries as they learn, which, in turn, helps them to develop a deeper appreciation for scientific measurement and data uncertainty, and to experiment with new ways of approaching scientific problems. Holmes' implementation of this type of intervention in an upper-level undergraduate physics laboratory class has shown "dramatic long-term improvements in students' quantitative critical thinking behaviors" (pp. 1-2) in comparison with a control group student cohort that experienced a more traditional 'cook-book'-style instructional approach.

Holmes' intervention shows a glimpse of the types of inquiry-guided learning that can be implemented in upper-level undergraduate physics courses. Further research into instruction and assessment in the context of large-scale introductory physics courses has generally focused on the implementation of increased active learning through flipped courses (Robert, et al., 2016; Wood et al., 2018; Ramlo, 2015; Tawfik & Lilly, 2015), whereas increased inquiry-guided learning has often been reserved for upper-level laboratory courses. Despite this, some researchers are working to bring inquiry-guided approaches to freshman-level undergraduate laboratory courses. At the University of Washington, Wagoner, Mairin Hines, and Flanagan (2018) have developed a flipped-style laboratory structure for an 850-student introductory physics course. Their approach hinges on students investing a significant amount of time on pre-lab preparation in order to devote their formal laboratory sessions to "focusing on the science of the experiment." (Wagoner et al., 2018, p. 244) Crucially, the researchers sought to engage students in the process of experimentation in order to retain "their natural inquiry, which [they] consider to be the most important attribute of a scientist." (p. 245) Their labs were structured according to two different models, 'Predict-Experiment-Assess' and 'Design and Experiment.' (p. 245) Well-defined rubrics became the backbone of their assessment structure, which provided 'checkpoints' for students to aim towards without offering them clear-cut, *cook-book* style instructions. Moreover, their desire to incite curiosity amongst their students was achieved by constructing narrative-style simulations to orient student experiments in situations that could be perceived as relevant to their day-to-day lives. However, despite their best efforts to create well-defined rubrics, the authors reported that grading consistency across the 24 lab sections by teaching assistants proved to be a significant challenge. At the end of the semester, students were asked to "quantify the improvement in their experience due to the lab changes" (p. 246) through the use of one Likert-style question. Though their results showed that students perceived these changes to have improved their learning experience, the structure of their research was unable to demonstrate any further quantifiable impact of this inquiry-guided pedagogical approach on student learning.

Although this review of relevant literature is far from exhaustive, as this framing shows, there continues to be a dearth of research into what degree of inquiry-guided learning is possible and pedagogically responsible in a lecture-based course for 500+ non-physics students. "We are now at a washershed in higher education," writes Wieman. "We are faced with the need for great change, and we have as yet unrealized opportunities for achieving great change." (Wieman, 2017, p. 10) The following research is an investigation into the intricacies of one such attempt to substantiate Wieman's vision of inquiry-guided learning in the context of a large-scale, prerequisite freshman physics course for Life Sciences students through the introduction of a *personalized learning* assessment scheme that included a group-project alternative to a standard multiple-choice midterm test. This process-oriented assessment style provided novice students—freshman non-physics majors—with the opportunity to creatively apply course content to an area of their own interest by asking students to create concept-bridging questions in pairs that explored real-life applications of electricity and magnetism. In the next chapter, we will outline the methodological approach used to understand the broader implications of this shift away from standardized modes of instruction and assessment and towards collaborative and exploratory learning at scale.

Chapter 3: Methodology

This chapter presents an overview of the methodological approach used to explore the implications of a personalized learning assessment scheme in a large-scale, prerequisite freshman physics course for Life Sciences students. In order to provide the reader with an appropriate grounding in this methodological approach, this chapter outlines the research context in question as well as the key objectives this study seeks to address. This chapter further describes the methods that were followed in order to gather both qualitative and qualitative data to answer the questions at the heart of this research, while taking into account study limitations that may have impacted these findings.

Research Context

Course description

The course featured in this research, Introduction to Physics—Electromagnetism, is an introductory prerequisite for all incoming freshmen Life Sciences majors enrolled at a large, public North American University. As a large scale course, it is taught to an audience of upwards of 500 students each Winter semester. Because it is a requirement for many programs in the Faculty of Science, every year there is considerable disparity between the incoming levels of mathematical training and exposure to fundamental physics concepts for this heterogeneous student demographic. This varied student demographic is registered in programs that include but are not limited to: Anatomy & Cell Biology, Biology, Biochemistry, Biological Physics, Chemistry, Computer Science, Cognitive Science, Economics, Kinesiology, Microbiology & Immunology, Mathematics, Nursing, Nutrition, Pharmacology, Physiology, and Software Engineering. For the majority of these students, this course represents their last mandated exposure to the principles and methods of physics during their undergraduate degree. Though most of these students will not go on to pursue careers in this field, a solid grounding in the laws of physics is necessary to enhance their understanding and appreciation of the natural sciences. (Physics Survey Overview Committee, 2001)

Through this introductory course, students are exposed to the topics of electromagnetism and optics by examining a set of concepts and laws that govern the physical behavior of electricity and magnetism. Students learn about and explore a wide range of concepts, such as electric charge, electric potential, currents, and magnetism, and discuss their application to topics like the working of household appliances, electric motors, power generation, all types of monitoring screens, defibrillators, MRI and PET scanners, the nervous system, light, lenses, optical devices as only some examples. The course offers students a combination of discussion and interactive problem-solving sessions in class and tutorials, pre-lecture preparatory reading, and laboratory practice. The objective of this course is for students to learn, understand, and apply the basic concepts and mathematical laws governing electricity and magnetism. As a learning outcome, students of this course should be able to apply these concepts and laws to synthesize solutions to new problems relevant to electromagnetism, at an undergraduate freshman level.

Course development

This study, which focuses on the implications of introducing collaborative and exploratory learning at scale, was conducted on the back of a multi-year program development project to improve the course' instructional design such that it was better aligned with the aims of student-centered learning. This broader program development project was developed by the course instructor, a senior faculty member of the university's Physics Department and myself, a graduate student in the field of education. The research featured in this study represents a collection of student feedback gathered from the fourth year of design interventions to restructure this course in order to provide the student demographic in question with a greater degree of active problem-solving and inquiry-guided learning.

During the semester when this study was conducted, the course featured a *personalized learning* assessment scheme wherein students could choose to opt in or out of select components of the course to help customize their learning experience. Certain components of the course remained mandatory for all students, namely lecture participation, weekly problem-based assignments (CAPA), a form of midterm assessment, the final exam, and participation in laboratory work. However, in addition to these mandatory components, students were given a month at the start of the semester to choose which of the additional course components they wanted to engage with and be graded on. These optional components included the pre-lecture reading assignments (Perusall), participation in tutorials, and their choice of either the midterm group project or the midterm multiple choice test. This flexible weighting scheme allowed for a variety of ways or streams through which students could navigate the same course. Although the brunt of research explored in this study focuses on how students engaged with their chosen type of midterm assessment, there is also allusion to the broader *personalized learning* structure of this course, particularly the tutorials and the pre-lecture readings.

Table 1

Personalized Learning Assessment Scheme Components

Personalized Learning Assessment Scheme		
Course components	**Percentage of final grade**	**Optional / Mandatory**
Pre-lecture readings (Perusall)	5% or 0%	Optional
Lecture participation	5%	Mandatory
Tutorials	10% or 0%	Optional
Problem-based weekly assignments (CAPA)	15%	Mandatory
Midterm group project	20% or 25%	Optional to midterm test
Midterm test	20% or 25%	Optional to midterm group project
Final exam	25% or 35%	Mandatory
Laboratory work	20%	Mandatory

Midterm group project description

For this first time in the structure of this course, students were given the opportunity to work in groups of two on a project aimed at consolidating and reinforcing their understanding of course concepts and their applications. Projects involved the development and solution of a multi-part problem that was built up by scaffolding multiple concepts covered in the course from the start to the middle of the term, approximately half of the topics covered up until that point in the course. Projects were assigned around midterm time and were due two to three weeks after being released. The directions students received for this assignment were very open-ended—students were directed to construct their own physics problem, based on course content, and apply it to a real-life scenario. For example, as will be further described in Chapter 4, one student chose to build a concept-bridging question that looked into the functioning of a household hair-dryer. Another student group wanted to better understand how electric charge and electric fields were applied to the hunting strategies of the electric eel. The project tasked students with using at least three of the course concepts to build their own problem and then present their own fully detailed solution to the problem they had created.

These projects were marked based on several categories to assess three levels of understanding (i. basic concept meaning; ii. appropriate formula use. iii. scaffolding concepts together). Assessment was based on a detailed rubric that was provided at the time of release of the project. (See Appendix C: Grader-Facing Midterm Group Project Rubric for more details.) Each student in the group received the same mark, but the projects needed to specify in detail each student's contribution. The instructor reserved the right to call on groups randomly to present their projects in a short oral presentation done online between the group, instructor and a TA.

Midterm test description

The midterm test, which was administered individually and in-person, was a multiple-choice format test that evaluated course topics covered up to approximately half way through the course.

Tutorials

The tutorials in this course were led by 32 undergraduate TEAM (Tomlinson Engagement Award for Mentoring) mentors who had demonstrated proficiency in this course in a previous year and chose to return to support the course instruction team as a peer-mentor. These weekly tutorials were held over 32 simultaneous Zoom breakout rooms, while the course professor invigilated the main breakout room and answered additional questions.

Teaching team

This course was instructed by a senior faculty-member of the university's Physics Department. The instructor led lectures on Zoom twice a week with the help of a teaching assistant (TA) from the Physics Department. In addition to leading the weekly virtual tutorials, one TEAM mentor was also tasked with mentoring students who opted into the midterm group project. This undergraduate mentor, along with the professor, held supplementary office hours with students participating in the group project to provide them with content-related support in the development of their project. In addition to these members of the teaching team, TAs from the Physics Department were tasked with grading the group projects, the final exam, and the lab assignments.

Virtual semester

Although this course is typically administered in-person, when this study was conducted, all the components of the course, except for the laboratory portion, took place online. This is because, according to the social distancing measures respected by the North American research university in question, all courses in the Winter 2022 semester with an enrollment number greater than 200 were forced to remain online, despite a broader loosening of pandemic-related precautionary measures.

Research Objectives

The objective of this research is not to weigh the merits of introducing self-directed learning into the purview of undergraduate students. This research is grounded in the premise that collaborative, exploratory learning is a preferred pedagogical approach for all students as discussed in Chapter 2. Rather, the objective of this research is to address the need, logistics, and impacts of a personalized learning assessment scheme in a particular educational context—the instruction and assessment of a prerequisite introductory physics course for Life Sciences students. Though not unique, this course stands out because of two primary factors: (1) its scale of over 500 students, and (2) its heterogeneous student demographic.

As a social scientist working within a Physics education context, my approach is not to prove a causal relationship between instruction and learning outcomes in this research when there are too many confounding variables at play. Instead, my aim is to explore the multidimensional implications of introducing alternative assessment styles into the formal education curriculum in order to better understand what is at stake when the stochastic, non-linear exploration inherent to the cultivation of a learner's curiosity is incentivized within a standardized education context where students have been conditioned to prioritize grade-based achievement.

The following study focuses on individual student experiences to understand the ways in which learning incentives are impacted once agency and choice are introduced into formal course assessment. It is not an attempt to quantify the unquantifiable impacts of this type of paradigm shift. Rather, this research seeks to shed light on the implications of qualitative assessment at scale for a highly grade-motivated student demographic—freshman students in the Life Sciences enrolled in a prerequisite course. By surveying and interviewing these students about their experiences, the aim was to understand not only what is possible from an instructional design perspective but to address the nuance of how students navigate a more flexible course structure.

Research Questions

The primary question at the center of this research is:

What are the implications of introducing learner centered instruction and assessment through a *personalized learning* assessment scheme that included a group-project alternative to a standard multiple-choice midterm test in a large-scale, prerequisite freshman physics course for Life Sciences students?

As a follow-up to this central question, this study also investigates the following lines of inquiry:

1. How did an assessment style that encouraged self-directed learning impact students' interest in the course content?
2. When presented with an element of choice in how they wanted to be assessed, what motivated students to choose a traditional multiple-choice exam versus an alternative project-based assessment?
3. How did Life Sciences students enrolled in a prerequisite freshman-level introductory physics course engage with open-ended, inquiry-guided research in the context of this course?
4. How does the introduction of a personalized learning assessment scheme impact a student's understanding of their approach to learning?

Methodological Framework

Student-centered research methods

As I alluded to in my opening remarks that sought to shed light on my reflexive relationship to this research, it is my understanding that the methodological framing of one's inquiry is perhaps as, if not more, influential on one's work than the questions being asked. According to this logic, I opted for a methodological approach espoused by Glesne and Peshkin (1992) who write that "rather than pursuing research with questions in search of the 'right' methods of data collection, I had a preferred method of data collection in search of the 'right' question." (p. 102) This preferred method of data collection centered around one basic premise—that student-centered learning should be studied according to student-centered research methods. What this meant for the purposes of my data collection was that the pedagogical interventions under investigation needed to be looked at from the perspective of the student experience. It is one thing to put a learning structure in place and infer learning impacts based on quantifiable results and another thing altogether to invite students to explain how and why this structure impacted their learning. As such, this research seeks to understand whether the pedagogical intention of this course structure was aligned with how it was experienced by the students it was meant to support.

Mixed methods sequential explanatory design

With a premise of student-centered research, a mixed methods methodological framework was chosen to structure this research because it was felt that neither a quantitative nor a qualitative approach would be sufficient to capture the full scope of the student experience. For the purposes of this research, the particular mixed methods approach that was chosen was a form of sequential explanatory design. Sequential explanatory design is carried out by collecting and analyzing data in two sequences, first quantitative data, then qualitative data over the course of a single study. Key to this approach is an understanding that the first stage of quantitative data collection provides the researcher with an overview of the research problem with statistical results, while the second, qualitative data phase offers a chance for more in-depth analysis based on individual participants' accounts of the issues under review. (Ivankova et al., 2006) A mixed-methods methodological approach allows for a combination of statistical and thematic analysis of the data collected. Because of the large scale of this class (500+ students), I felt it was necessary to include a quantitative approach in order to better understand the big picture trends presented by the class as a whole. However, it was also important to dive deeper into the perception of individual students to better identify why and how the *personalized learning* assessment scheme had an impact on their learning in and appreciation of the course content.

Implications of mixed-methods sequential explanatory design

When it comes to the implementation of mixed-methods sequential explanatory design, there are two key issues that need to be taken into account. The first is the issue of priority, which refers to the researcher's challenge to find the balance between the significance they put on the quantitative versus the qualitative portion of their data. The affordance chosen by the researcher depends greatly on their own subjective nature and/or their intended audience. (Ivankova et al., 2006, p. 9) In this study, although the quantitative data allowed me to investigate trends in student responses, further investigation into these trends through the qualitative data collected allowed me to make sense of the student experience. Quantitative and qualitative methods can often seem at odds with each other as the former uses predictive categories to understand the patterns in a given scenario and the latter is an amorphous process of “culling for meaning from the words and actions of the participants in the study.” (Maykut, 2010, p. 118) However, when used sequentially, the larger trends identified in the quantitative phase of mixed-methods research can serve to orient the qualitative data collection protocols, which in turn provide more depth and meaning to the research. (Ivankova et al., 2006, p. 11)

Implications of quantitative research

In order to record measurements, the nature of the data being collected must be stable to provide a snapshot of the reality at hand. This stagnant depiction of data may be a useful tool to compare and contrast distinct measurements, but it can never depict the full array of a dynamic process such as attitudes to learning. (Punch, 2009, p. 238) In educational research, the nature of what is being studied is not “directly observable,” such as the notion of *intelligence* or *learning*. Thus, it becomes necessary to assess abstract concepts through the use of latent characteristics that merely infer what cannot be known explicitly. (Punch, 2009, p. 239)

Implications of qualitative research

Much like in many qualitative studies, the real interest of this research lies in trying to get a better sense of how its participants make sense of their own experience and how this perspective then informs their actions, rather than an attempt to determine precisely what happened in a given environment. (Glesne & Peshkin, 1992) Because of the highly qualitative nature of this study, I, the researcher, become the primary research instrument collecting and interpreting the information that I perceive. As such, this approach to research is inductive by default, which means that it must retain a certain level of methodological flexibility in order to respond to emergent insights. These new insights then offer a new lens into which the data can be investigated anew. Qualitative researchers often don’t develop their final research questions until they have done a significant amount of data collection and analysis. Well-constructed, focused questions are generally the result of an interactive design process, rather than being the starting point for developing a design. (Maxwell, 2012) Although the findings shown in the research were gathered from the perspective of a mixed-methods methodological framework, by the time this research was conducted, I had spent three previous years working in this course. I was, thus, highly familiar with the type of students who take the course and had observed the course dynamics in depth with insight into the pedagogical intentions of the instructor.

Implications of interviewing

According to Whetherell (2003), a critical perspective on the interview process allows us to understand that knowledge is negotiated and enacted through the dialogical process of exchange. Interviewing, thus, allows the researcher to delve into how others “organize their versions of events, and how they build identities for themselves and others as they speak.” (p. 11) It must be recognized that it is the responsibility of the researcher engaged in discourse analysis to recognize that they are not in the position to be the arbiter of truth claims in the interpretive process. Rather, the researcher’s responsibility is to reflexively account for the co-construction of knowledge that emerges as a consequence of their own entanglement within the production and interpretation of the discursive process. (Whetherell, 2003)

My own understanding of the complex nature of interviewing can be summed up in the following excerpt: “Every word that people use in telling their stories is a microcosm of their consciousness. Individuals’ consciousness gives access to the most complicated social and educational issues, because social and educational issues are abstractions based on the concrete experience of people.” (Seidman, 2006, p. 7) A critical perspective on the interview process allows us to understand that knowledge is negotiated and enacted through the dialogical process of exchange. Thus, interviewing allows the researcher to delve into how others “organize their versions of events, and how they build identities for themselves and others as they speak.” (Whetherell, 2003, p. 11)

Research Methods

As noted earlier, the study featured in this research followed the methodological structure of a mixed-methods sequential explanatory design. What this implies is that there were three broad phases that went into the findings presented in the next chapter. First, a survey was administered to willing students from the large-scale introductory physics course under study. Second, consenting survey respondents participated in individual, virtual follow-up interviews after the academic semester was over. The final step was my interpretation of the results, which, as is detailed in my fifth chapter, underwent an epistemological shift in the overarching lens through which I interpreted these findings.

All students enrolled in Introductory Physics—Electromagnetism in the Winter semester of 2022 were invited to participate in this study through general class announcements on the virtual course platform. (See Appendix A: Sample Recruitment Script) In the recruitment script, students were given a brief summary of the study with full freedom to participate or not. Those who agreed to participate were directed to an MS Teams survey and were provided with a more detailed description of the study as part of a written informed consent document. Students were assured their data would remain completely confidential and would in no way influence their performance in the course or any subsequent courses at McGill. Students could withdraw from the study at any time. This study was approved by the McGill Research Ethics Board under the file number 22-03-113.

Students who agreed to participate in the study were first asked to fill out a short survey including both Likert scale and short answer questions in line with their midterm assessment choice, at the very end of the semester, during the week leading to their final exam. (See Appendix D: Survey Questions) At the end of this survey, students were asked for their consent to participate in a recorded interview, two weeks after the end of the course. (See Appendix E: Interview Questions) These follow-up semi-structured interviews, which lasted approximately 30 minutes each, were designed to further probe their experience as part of the class and provide further explanation as to their experience with either the midterm group project or the midterm test. These interviews were conducted by myself and an undergraduate TEAM mentor, Peter El Khoury, who had served as the mentor providing content-related support for the group projects, alongside the course instructor.

Student participant information

The survey was not anonymous and students had the option to give their consent in order for their grades to be shared in this study. In this study, student participants have been given pseudonyms to protect their privacy. 34 students enrolled in 26 different undergraduate programs responded to the student feedback survey. 22 of the student participants were in their freshman year (U0), 9 were in the second year of their undergraduate degree (U1), 2 students were in the third year, and 1 student was in their fourth year (U3). Of the cohort of students who responded to the student feedback survey, 8 agreed to take part in the follow-up interview. Of these interview participants, 4 had chosen the midterm project and 4 had chosen the midterm test. A breakdown of the profiles of the interview participants is shown in the following Table 2 (next page).

Table 2

Interview Participant Student Profiles

Interview Participant Student Profiles				
Student Pseudonym	**Faculty**	**Degree Program**	**Degree year**	**Midterm assessment choice**
Midterm Test Student 1	Faculty of Science	Biological, Biomedical, and Life Sciences	U0	Midterm test
Midterm Test Student 2	Faculty of Science	Biological, Biomedical, and Life Sciences	U1	Midterm test
Midterm Test Student 3	Faculty of Arts and Science	Economics and Computer Science	U1	Midterm test
Midterm Test Student 4	Faculty of Science	Biology	U0	Midterm test
Midterm Group Project Student 1	Faculty of Science	Neuroscience and Physiology	U0	Midterm project
Midterm Group Project Student 2	Faculty of Science	Microbiology and Immunology	U0	Midterm project
Midterm Group Project Student 3	Faculty of Science	Undisclosed	U0	Midterm project
Midterm Group Project Student 4	Faculty of Science	Biomedical Science	U0	Midterm project

Data collection

The first data collection process consisted of a bifurcated survey to probe the learning experience of two distinct cohorts of the students enrolled in this course (See Appendix D: Survey Questions). The survey started with an initial question addressed to all survey respondents and then followed two streams to better quantify and quality the impacts of the midterm test and the midterm group project on students' engagement with the course content. The questions consisted of (1) identifying questions, (2) Likert-scale questions, (3) open-ended, long- and short-answer style questions about their experience in course. This survey was shared with the entire class at the end of the semester so as to gather accounts of the student experience after they had received their final mark in the course. A total of 34 students from the course agreed to take part in this survey—18 of these students had opted into the midterm test and 16 of them had opted for the midterm group project. This proportional breakdown mirrors the choices of all students in the course. This survey mainly consisted of Likert-scale quantitative feedback that gauged students' responses to a set of statements tailored to classify the experience according to perceivable outcomes for each student cohort. These statements allowed me to create understandable profiles of both cohorts and provided me with a more general idea of how students engaged with the course. For both groups, these Likert-style questions were followed by two or three open-ended questions that allowed students to further describe the impact of the *personalized learning* assessment scheme on their engagement with the course.

The second data collection phase entailed semi-structured interviews with consenting survey respondents, which took place on Zoom two weeks after the end of the semester. The interviews were a means to go more into depth based on the data collected in the student survey. The questions asked were more open-ended and pertained to their experience in the whole course, though particular focus was placed on their experience with their chosen midterm assessment style. The purpose of these interviews was to provide an in-depth understanding of how each student engaged with the course, what components of *personalized learning* assessment scheme they opted into, why they chose to be assessed that way, how their participation in different elements of the course impacted their learning, how their choice of the midterm project or test impacted their appreciation and understanding of the course content.

Thematic Analysis

Inductive coding was used in the analysis of all of the open-ended data collected from both the student feedback survey and the interview transcripts. As described by Maykut and Morehouse, "[t]he process of qualitative data analysis is one of culling for meaning from the words and actions of the participants in the study, framed by the researcher's focus of inquiry." (1994, p. 118) As a highly interactive and subjective process, inductive coding allowed me to build a more complete look at the themes throughout the long-answers and discussion-based data collected in this study. (Tashakkori & Teddlie, 2010) In trying to understand the highly subjective process that is qualitative data coding, I turned to the explanation of Maxwell and Miller (2008), who write that, because this method of parsing information is premised upon linguistic analysis, the researcher must take into account a category distinction between two types of related data: "those based on similarity and those based on contiguity." (p. 461) This approach to categorization shifts the perspective of the researcher to recognize not only straight-froward similarity or difference amongst student responses but to ground the data analysis in "contiguity-based relations." (p. 462) Contiguous framing demands a level of analysis that is bound in the interrelation of perspectives and contexts, often by employing the element of time to better understand how narrative experience evolves throughout the course of a study. For the purposes of my own research, it is this lens of *contiguity* that allowed me to better understand the transformations that took place because I was able to better situate the experience of the students represented in this study within the broader context of their freshman academic year.

Throughout the analysis of this case study, my approach to coding the interview transcript data collected from eight students entailed an initial semantic investigation into emergent themes in each individual interview. As described by Mawell and Miller, the process of qualitative coding is one of “decontextualizing and recontextualizing” (2008, p. 465). My approach entailed many iterative layers of semantic investigation. Though I had conducted the interviews, my understanding of each student profile required me look into not only what was said in the interviews but how the students' reflections and insights played into the broader ways in which they engaged in the different instructional and evaluative elements of the course. In doing so, I was able to draw broader insights into patterns of behavior between groups of students, which led me to reread the interview transcripts in a new light. Through thematic coding, the overarching emergent themes could be further broken down into distinct subcategories that are reflected in my findings and analyses.

In order to increase reliability in the interpretation of these findings, the inductive themes were identified independently between myself and the undergraduate student with whom I conducted the interviews, Peter El Khoury. The central emergent themes resulting from this first coding process were then compared to ensure a greater standard of reliability in the highly subjective qualitative data coding process. Because of the open-ended nature of much of the data collected, there was a need to follow a constant comparison inquiry approach. Constant comparison inquiry gradually refining broad, amorphous categories into increasingly clear distinctions between qualitative data. (Butler-Kisber, 2018, p. 46) This labor-intensive process allowed me to distinguish clear thematic categories out the transcript and long answer responses from the survey. The findings presented in this research reflect an articulation of the core themes that emerged from this analytical process.

Methodological Limitations

Timing constraint and lack of anonymity

The data presented in this study was collected at the end of the semester in order to allow the student participants to have a broader perspective on their experience in the course after they had finished the final exam. Unfortunately, this meant that fewer students were willing to take part in the follow-up portion of the study. Furthermore, because we were looking to compare the survey and interview data to how each participant performed in the course as a whole, we required that the data not be anonymous. Revealing their identity may have dissuaded many student participants from taking part in this study.

Student survey fatigue

An initial mid-semester feedback survey was conducted directly following the submission of the midterm assessment in order to collect feedback about student experience in the course at that point in the semester. This data was collected within the context of course improvement and was fully anonymous. This survey received over one hundred responses. However, what is shared in this study only corresponds to the data collected with ethics approval REB 22-03-113.

No study participation incentives

It is important to note that no incentives were given to students as compensation for their participation in this research. Students were, however, told that their insight and experience would contribute to the structure of future iterations of the course.

Self-reporting bias

Students who agreed to respond to study were self-selected, this opens the door to question how representative these students are of the whole course. Luckily, of the students who agreed to be interviewed, there was equal representation between both the midterm test and midterm projects students. Furthermore, there is additional alignment between the study respondents and the class as a whole because the percentage breakdown of students who answered survey is in line with course-wise midterm selection.

In conclusion, this chapter provides a methodological context to explain the aims, questions, research design, and methods used to gather the student-centered data that was collected to better understand the implications of introducing learner centered instruction and assessment through a *personalized learning* assessment scheme in a large-scale, prerequisite freshman physics course. A mixed methods explanatory sequential design approach was used to first survey a subset of the students (N=34), which was followed-up by an interview to select participants (N=8) about their experience in the course in order to better understand not only how students engaged with the course components, with particular emphasis on their choice of midterm assessment style, but also to address the nuance of how individual students chose to navigate a more flexible assessment scheme that created space for collaborative and exploratory learning. In the next chapter, we will explore how the responses to the student survey and interviews informed my analysis of the findings in relation to research questions.

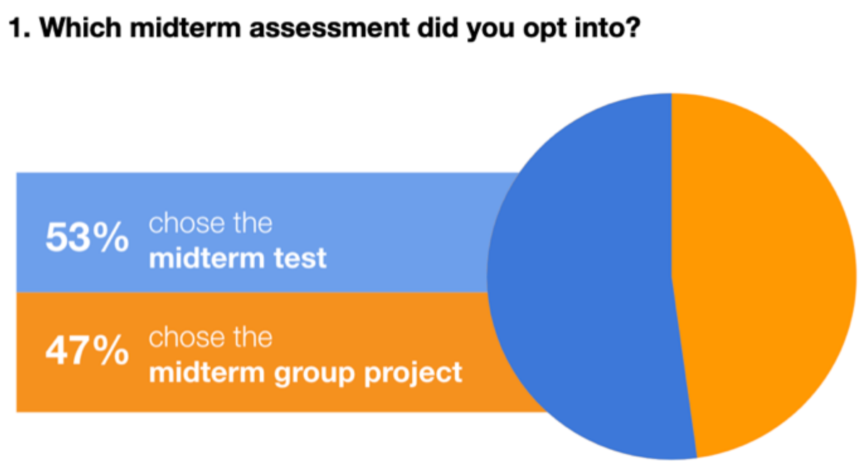
Chapter 4: Findings and Analysis

This chapter covers the findings gathered from surveying and interviewing students about their experience with the personalized learning assessment scheme outlined in the last chapter. These findings are based on the qualitative and qualitative data collected from students enrolled in a large-scale, prerequisite introductory physics course for Life Sciences students. My portrayal of these findings seeks to highlight the similarities and differences in experience between students who opted into the midterm test and the midterm group project. As you will see, both the survey and interviews were bifurcated between the two student cohorts in order to better understand how each group of students navigated their chosen assessment style (See Chapter 3 and Appendix D).

Survey Responses

The student feedback survey started by asking all student respondents which midterm assignment they had opted into. 34 students responded to the survey. Of the total group of survey respondents, 18 students had taken the test and 16 students had done the midterm group project. As you can see in the figure below, 53% of the respondents had chosen the midterm test and 47% had chosen the midterm group project. The percentages reflected in the survey responses mirror almost perfectly the midterm assessment choices of the class as a whole—54% of the entire class opted in to the midterm test versus 46% of the class who opted in to the midterm project.

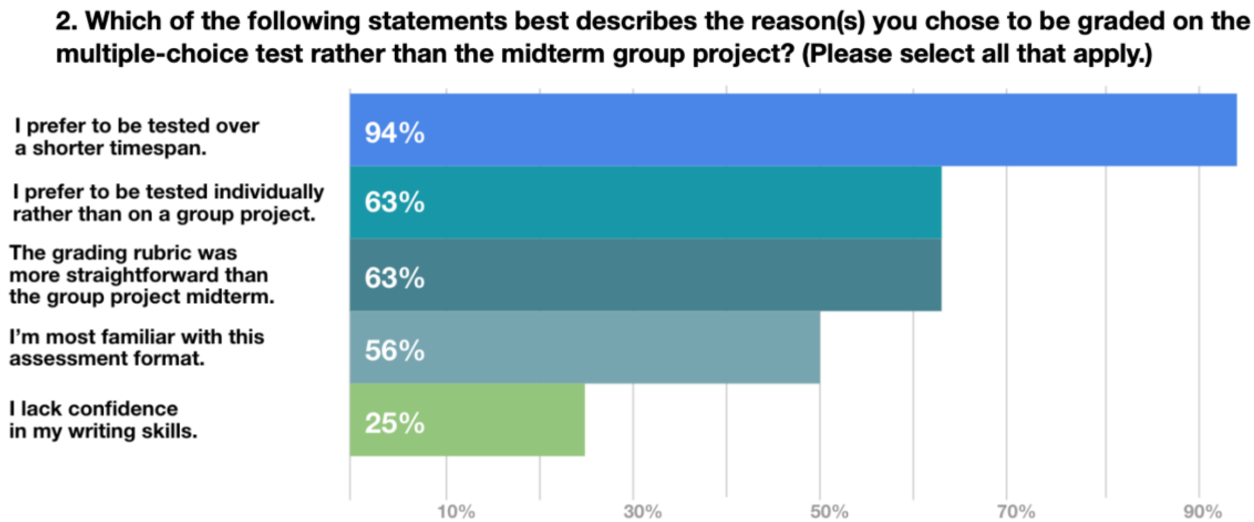
Figure 1*Survey Question 1 to All Respondents*



The subsequent portion of the survey was directed at the midterm test students. These students were asked to identify which of a set of statements best described the reasons they chose to be graded on the multiple-choice test rather than the concept-bridging group project as detailed in the methodology chapter (see Chapter 3).

Midterm Test Students

Figure 2 *Survey Question 2 to Midterm Test Students*



As you can see from this figure, 94% of students reported that they preferred to be tested over a shorter timespan; 63% said they preferred to be tested individually rather than on a group project; 63% also said that they felt the grading rubric was more straight-forward on the midterm test than the midterm project; 56% responded that they were most familiar with a test assessment format, and 25% admitted that they lacked confidence in their writing skills. These responses show that, although there are other factors that went into their decision to choose the midterm test, the vast majority report an overwhelming desire to opt for the more efficient assessment style.

This question was followed by a multi-part Likert-scale portion of the survey that sought to gauge how students from both groups—midterm test and midterm group project—identified with 19 statements about their learning experience with the midterm test (see Appendix D). These statements followed five different categories.

1. The first grouping sought to get a better understanding of their intentions going in to the midterm test.

2. The second grouping focused on students' self-identified beliefs surrounding their test-based performance.
3. The third grouping probed into how they felt about their learning after they had taken the exam, both based on their perceived performance and the feedback they received.
4. And the final grouping concerned their general interest in research and their desire to pursue educational opportunities that allowed for applications of their learning.

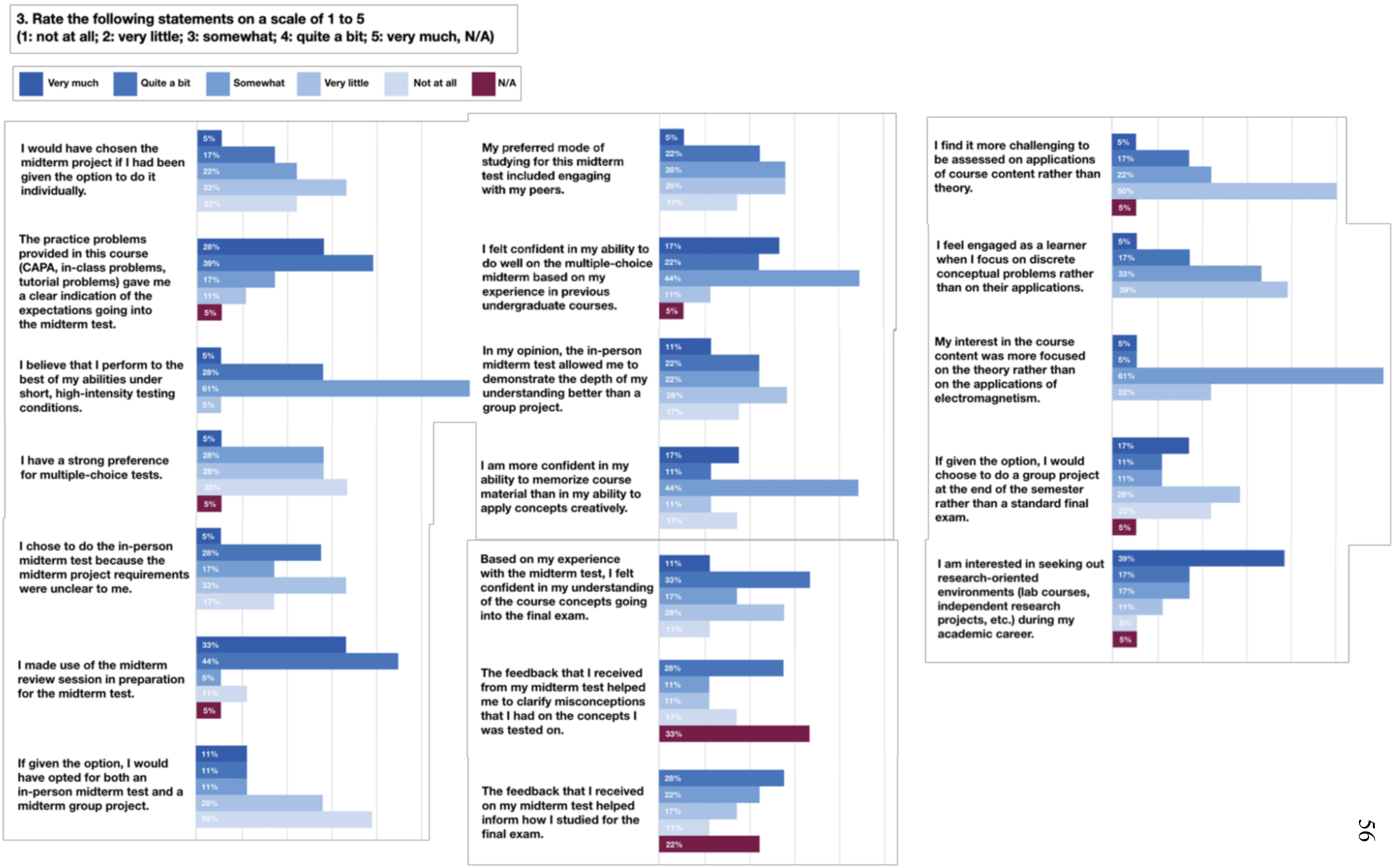
The full-page Figure 3 on the next page illustrates the responses from the 18 students who had chosen the midterm test. The findings suggest a few trends amongst this student cohort. Students do not express that they think the test-style evaluation offered them a better option to demonstrate their learning. Instead, the findings show that these students opted into the test because it offered them a mode of evaluation in which they were relatively confident they could do perform well on. For example, a total of 83% of respondents answered that they either 'very much,' 'quite a bit,' or 'somewhat' "felt confident in my ability to do well on the multiple-choice midterm based on my experience in previous undergraduate courses." That being said, when asked bluntly if they had "a strong preference for multiple-choice tests," 61% responded either 'very little' or 'not at all.'

These findings also show that, although 73% of these students were interested in "seeking out research-oriented environments" during their degree, 71% reported that they were at least 'somewhat' more engaged as a learner when they focus on discrete conceptual problems rather than their applications. We see that 72% feel more confident in their ability to memorize course material than to apply concepts creatively. However, we can also notice that, in preparation for the midterm test, 82% of these students attended the midterm review session which indicates that they got as much help as they could in order to perform well on the test. Furthermore, 67% of respondents reported that their experience with the test informed how they studied for the final exam. In all, we see clear demonstration that this student cohort is concerned about their grade-based performance in the course (Figure 3).

Following these Likert-style questions, the midterm test students were asked to respond to two open-ended questions. The first of these long answer questions inquired into their perception of the learning benefits and/or disadvantages of a project-style midterm versus a multiple-choice test, based on their experience with the multiple-choice test. The following table compares the learning benefits of each assessment style outlined by these students. As the table indicates, even

Figure 3

Survey Question 3—Likert-style Questions to Midterm Test Students



students who opted for the test were able to identify more learning benefits from the midterm project option than the multiple-choice test. The one clear learning benefit in favor of the test was the requirement of students to demonstrate their understanding individually. Other benefits alluded to were less focused on learning and more geared toward the logistics of a test in that the test required a shorter investment of time and that provided better preparation for future exams.

Table 4

Learning Disadvantages of Each Assessment Style Outlined By Midterm Test Students

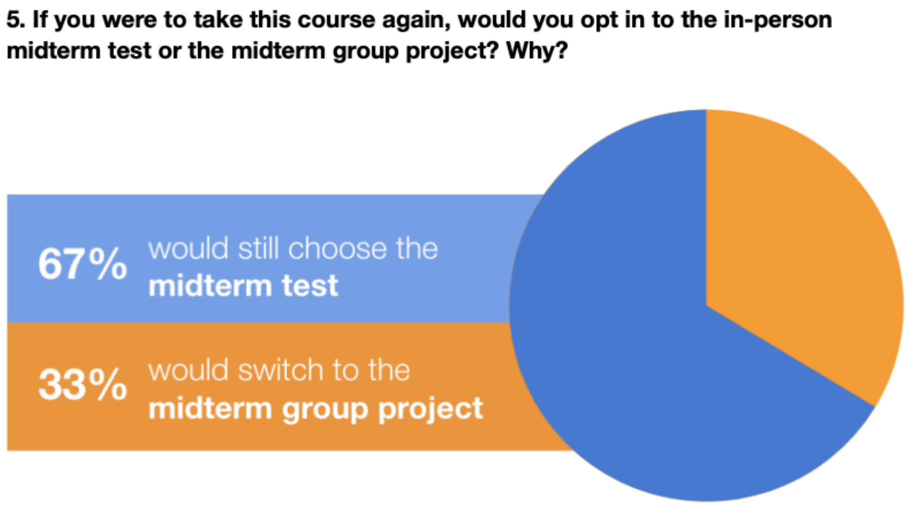
Learning Disadvantages of Each Assessment Style Outlined By Midterm Test Students	
Midterm Test	**Midterm Project**
A test forces the memorization of key words	Sacrificing breadth of understanding for depth of understanding
It's harder to learn from your mistakes on a multiple choice test because you don't have access to why you came to a certain answer	Potential for grade to not fully reflect student understanding because of research opportunities and the collaborative nature of the work
Small mistakes lead to a total loss of marks because of no partial marks	Students were less prepared for the final exam / heightened stress on the final exam
Learning is geared toward 'learning for the test'	Less stress but longer time commitment
High stress due to high pressure during a short timeframe	More space for grader subjectivity
Multiple choice test does not fully reflect a student's lack of understanding on a given concept	

What we learn from these answers is that, although students recognized learning benefits associated to the project, they chose the midterm project because it allowed them to spend less time and effort on learning the course content and best prepare them to do well on the final exam. That being said, of the students who picked the multiple-choice test, many would have preferred a long answer-style test in order to be able to show their process through a problem.

The second open-ended question asked students whether they would, once again, opt into the midterm test or whether they would switch to the midterm group project if they were given the option to retake the course. In response to this question and, despite having outlined the increased learning benefits of a project-style assessment, 67% of these students answered that they would still choose the midterm test (see Figure 4).

Figure 4

Survey Question 5 to Midterm Test Students



When asked to describe why, these students articulated that, although they saw value in the exploratory aspects of a midterm group project, they preferred the straight-forward nature of the test in the context of this particular course. Aspects that played into this hypothetical decision were their preference to be graded individually, their confidence in their test-taking abilities, their perception that preparation for the test would require less time and effort of them, and their general disinterest and discomfort with being assessed in an unfamiliar way. Table 5 complements these themed takeaways with direct quotes from the students' survey answers. What we notice from the answers of this cohort of students is that they had well-defined reasons for opting once again to be assessed by a test rather than a project. Students noted their confidence in their test-taking abilites and their preference to be graded individually as key reasons to stick to a test-style assessment format. However, some students also felt strongly that a test would provide a better indication of their understanding of the course content than a project: "[B]eing able to answer questions correctly is a much more effective way to demonstrate understanding than a project. A project demonstrates how good someone is at researching, whereas a test shows how well someone understands the content."

However, 33% of these students answered that they would have chosen to switch to the midterm group project. As Table 6 indicates, the main reasons students would have changed their assessment style were because, in hindsight, the project offered greater grading leniency and because it allowed for more in-depth demonstration of student understanding in a lower stress context. One student expressed that, even though they disliked multiple-choice tests, the subjective-nature of the rubric made the project seem like a higher-risk choice when it came to securing a good grade. Another student mentioned that, in hindsight, the project would have provided him with a better opportunity to get a good grade while also improving his understanding on particular course concepts: “[I] could have focused on a very specific part of the material and deepened my knowledge hence get a better grade.”

In all, we see that the students who opted into the midterm test did so for highly pragmatic reasons (Table 5). These students value their time, both going into the midterm and in preparation for the final exam. Choosing the multiple-choice test was, largely, a choice in favor of saving time and effort in the short- and long-terms. That said, these students still acknowledge that it is beneficial to their learning to understand real-life applications of the course concepts and that the midterm group project would have given them an opportunity to do just that.

Table 5

Reasons Reported By Midterm Test Students for Sticking to the Test

Reasons Reported By Midterm Test Students for Sticking to the Test			
Preference to be graded individually	"The test, because I prefer individual work and don't want to risk getting a bad partner despite the fact that the group project grades were higher on average than the test."	"I didn't really have any friends in the course, and I have had bad experiences working with strangers in the past - you just don't know what you're getting into."	"I would opt in to the midterm test again since I dislike such a large part of my grade relying on a group project. It's nice if you can find a good match for a partner however sometimes this isn't the case therefore I would take the test again due to that risk."
Shorter time frame	"I would still do the midterm test since I like the finality of a test as opposed to a longer-term project."	"I would choose the in-person test, largely because it is much less time-consuming than the group project. "	"I find it easier to study for a test and just write it at once instead of having to come up with an idea and work on it over an extended period of time."
Grade optimization with less investment	"[T]o be honest, I enroll for these 2 course just in order to satisfy my general science requirements in the easiest way. And I choose the test over the project as the easier way of the two."	"I got a good grade, and to get the same grade from the project would be much harder, and require more effort."	"I felt that my grade would be better. I typically get better results solving problems than writing assignments."
Confidence in test taking abilities	"I would opt in to the in-person midterm test once again, since I think I perform well in exams that I am prepared for. I think exams are more straightforward, the answers are either correct or wrong."	"I am better at taking exams than doing projects that requires more creativity. In addition, I believe it takes much more work to come up with a good project."	"I didn't believe I would have the understanding and creativity to come up with a project idea."
Feeling that the test is a better indicator of depth and/ or breadth of understanding	"I would argue that the midterm test had more depth than the project as it required us to practice the material and apply it to theatrically worded questions. Since the students who chose the project could use their notes or the internet they could offload some of the technical understanding to their resources."	"[B]eing able to answer questions correctly is a much more effective way to demonstrate understanding than a project. A project demonstrates how good someone is at researching, whereas a test shows how well someone understands the content."	"I think in some ways, this assessment style allowed me to demonstrate the depth of my understanding better than a group project. […] The test made me reflect on exactly what topics I mastered and which I needed to work more on. I was tested on a broad number of things, which demonstrated the breadth of my understanding."
Better preparation for the final exam	"[I] would still opt in for the midterm test because since there's a final exam, might as well spend my time studying the full midterm material when there's the midterm and then when there's the final i can focus on the post midterm content."	"I felt that by taking the midterm test, it would help me clear up any confusions or misunderstanding earlier in the semester and help me realize which areas of the course I need to study more for the final."	"I thought it would better prepare me for the final since the final is an examination"
Discomfort with uncertainty of open-ended project-style assessment	"[S]ince it is a group project, the grading is flexible and unpredictable even it comes with a criteria--So students may feel they meet the criteria but still lose some or many points. I don't want to spend so much time on a group project that may end up receiving a low or average point, especially when the project is worth 20% of the grade of the course.	"[T]he test felt safer to me as the grading is not at all subjective, and i'm more familiar with preparing for tests rather than projects."	"I also prefer multiple choice evaluations in general because they aren't open-ended."
Discomfort with creative application of course concepts	"The midterm test seemed much more straight-forward to me, while the group project was very abstract. Although I see the value in coming up with questions that combine multiple topics and applications, my brain just isn't creatively-inclined in that sense."		
Increased motivation to understand and review course concepts	"I felt more motivated to review and understand concepts when preparing for the exam."		
Disinterest in physics content	"Although, i loved the concept of the midterm group project, I am not very interested in physics and did not feel like researching its applications in personal fields of interest."		
The lectures provided sufficient discussion of the application of course content	"I felt that there were enough applications of electromagnetism discussed in class that the curious part of me was satisfied. Although the project seemed very interesting, I felt that I was still able to gain an adequate understanding of such applications without it."		

Table 6

Reasons Reported by Midterm Test Students for Switching to the Group Project

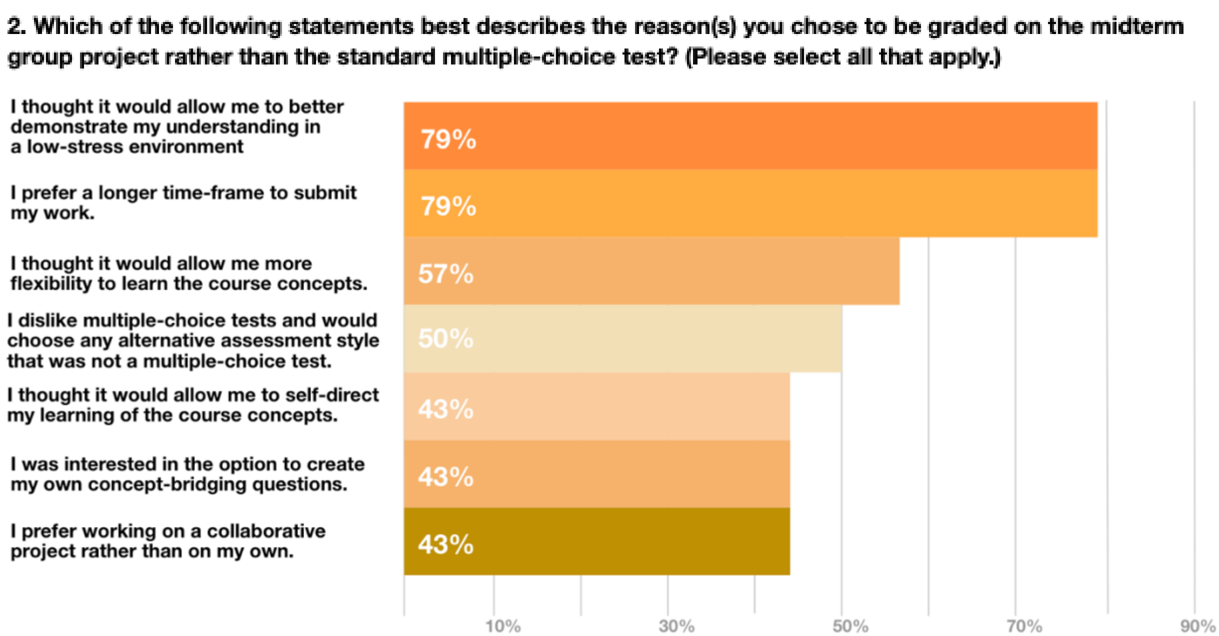
Reasons Reported by Midterm Test Students for Switching to the Group Project			
Grade optimization due to increased grading leniency of the project	“Ultimately, I am in physics 102 because it is a prerequisite for my program, and I want to do the best in it I can do. I found the midterm test extremely challenging, considering the time provided. All my friends who did the project scored 95-100%, while I received a 73% on the midterm after the curve. I took the midterm because I was relatively confident in my understanding of the course, wanted to get some practice before the final and often helped my friends on the CAPAs. Thus it was a bit disheartening to do so poorly in comparison to them.	“The rubric seemed to be very subjective initially and did not clearly outline expectations for success. which I why I had decided to write the midterm test, though I do not enjoy multiple choice exams. However, the midterm project ended up having a MUCH higher average than the midterm test which demonstrated a not-as-strict grading scheme as the midterm test.”	“If I were to retake this course again, I would opt for the midterm group project because the overall average of the midterm group project was significantly higher than that of the midterm test.”
Allowed further demonstration of understanding with less stress	“If the test had more time, I think it would have been a good indicator of my abilities, but even with the curve, I do not think my grade accurately represented my understanding. At least, for the project, I would have had all the time I needed to demonstrate this, which was kind of the reason I chose the test, so I wouldn't be spending lots of time on this, when I had other exams to study for, but in the end, the project would have been more suited towards me.”	“I also feel that multiple-choice assessments do not accurately demonstrate the comprehension of course material because even if all the steps were right, it is possible a small calculation error causes the whole question to be wrong. Thus, despite the understanding of the question, in multiple-choice assessments, the only thing that is shown in your final answer and therefore the comprehension of course material is not adequately depicted.”	“I felt like the midterm test did not show accurately my understanding of the concepts. A large reason for this was the time pressure. I felt very stressed when writing the test, because, for almost all questions, calculations were necessary and time consuming (at least for me) and even though I thought I understood the material, I was very stressed right of the get-go due to this short time constraint, and wasn't able to answer all the questions to the best of my abilities.”
Ability to demonstrate depth of understanding	“[I] could have focused on a very specific part of the material and deepened my knowledge hence get a better grade.”	“I think the group project would have demonstrated my depth of knowledge better. Even though I did well on the test, I think it was more repeating knowledge, whereas the project would have been applying the knowledge more. By applying the knowledge, I would have been able to demonstrate my depth of knowledge better.	“[T]he project would’ve allowed me to demonstrate the depth of my understanding since i’d be creating problems based on what i’m grasped from the course and how it can be applied to the real world, which in my opinion is significantly more important than being able to cram for a test that doesn’t allow students to demonstrate any sort of deep understanding of the concept especially since it was multiple choice and no work could be shown.”

Midterm Group Project Students

Next, the following portion of the survey was directed at only the students who had chosen the midterm group project. These students were asked to identify which of a set of statements best described the reasons they chose to be graded on the concept-bridging group project rather than the multiple-choice test. As the following Figure 5 indicates, 79% of the 16 respondents thought the project would allow them to better demonstrate their understanding in a low-stress environment. Similarly, the same percentage of students preferred a longer time-frame to submit their work. 57% of these students thought it would allow them more flexibility to learn the course concepts and 50% said they expressly disliked the multiple-choice option. Finally, 43% of the midterm project students also felt that (1) their choice would allow them to self-direct their learning, (2) they were interested in the option to create their own concept-bridging questions, and (3) they preferred working on a collaborative project to working individually.

Figure 5

Survey question 2 to midterm group project students



These midterm project students were then asked to describe which concepts from the course they had incorporated into their concept-bridging questions. Their answers varied, but many reported that their projects covered almost all, if not all, of the topics from the beginning of the semester until the midterm. For example, one group who chose to focus on how a bionic leg worked, incorporated circuits, electric fields, and capacitors. Another ambitious team went as far as to include electric charge, Ohm's Law, equivalent resistance, capacitance, and energy. Students noted that they tried to touch on as much of the first half of the semester's content as they could.

This question was followed by a multi-part Likert-scale portion of the survey that sought to gauge how students identified with 24 statements about their learning experience with the midterm group project (Appendix D). These statements followed five different categories. The first grouping sought to get a better understanding of their intentions going in to the midterm project. The second grouping focused on students' self-identified beliefs surrounding their project-based performance. The third grouping asked about their overall interest in the course content and preference to learn based on applications rather than theory. The fourth grouping was interested in this student cohort's experience of the final exam. The fifth grouping was geared toward learning takeaways from the midterm project and the final grouping concerned their general interest in research and their desire to pursue research-oriented educational opportunities that allow for applications of their learning. The full-page Figure 6 on the next page illustrates the responses from the 16 students who chose the midterm group project.

These findings show a noticeable difference compared to those of the midterm test takers. In contrast to much of the apathy of the previous cohort, these students' answers reflect strong feelings in favor of their choice of midterm assessment. 88% of these students reported that the project helped deepen their understanding of how concepts in the course were interrelated and 94% said it increased their understanding of how electromagnetism relates to other scientific fields. 68% felt that their interest in electromagnetism was at least 'somewhat' piqued by the exercise of creating their own questions. 93% agreed that this assessment style allowed them to demonstrate the depth of their understanding better than a standard multiple-choice test. And if given the option to do a second group project at the end of the semester rather than a standard final exam, 87% said that would be their preferred choice (Figure 6).

Furthermore, 75% of these students used this opportunity to incorporate content related to their field of study into the questions they designed. A total of 88% of respondents agreed that applying electromagnetism concepts to real life scenarios made learning the course material more enjoyable and 94% stated that the open-ended nature of the project encouraged them to research content beyond the scope of this course. Finally, 87% of these students felt that they had a stronger grasp of the concepts they applied in the midterm project than they did on the content from the second half of the semester. These findings also show that, despite it being a group project, students were able to do a lot of the work primarily on their own and that the discussions they had with their group partner improved their understanding of the course content. However, we also can see that students did not receive enough feedback on their projects to help them clarify misconceptions on the concepts they had applied and that the feedback they did receive on their work largely did not inform how they studied for the final exam.

Like with the first student cohort, following this set of questions, this second group of students were asked a series of three open-ended questions to give them the chance to describe their experience with the midterm group project in their own words. The first of these questions asked them to outline some of the learning benefits and/or disadvantages they could think of between the two assessment styles. As you can see in the following table (Table 7), the students who chose the midterm project could not name a single learning benefit of the multiple-choice test option. In contrast, the categories that came up in favor of the project were that the creation of their own problems provided for a better demonstration of their understanding and that this assessment style increased their understanding of and curiosity in the course content partly because students got to choose what content they were being evaluated on. Students also pointed out that the project-style midterm relieved stress around being evaluated because students could pace their own learning and had more time to explore the course content on their own. However, in terms of disadvantages of the project, these students did allude to difficulties in collaborative work and a sacrifice of the breadth for the depth of their ability to demonstrate their understanding, which did allow for them to ignore certain content that they did not want to engage with (as seen in Table 8).

Figure 6

Survey Question 3

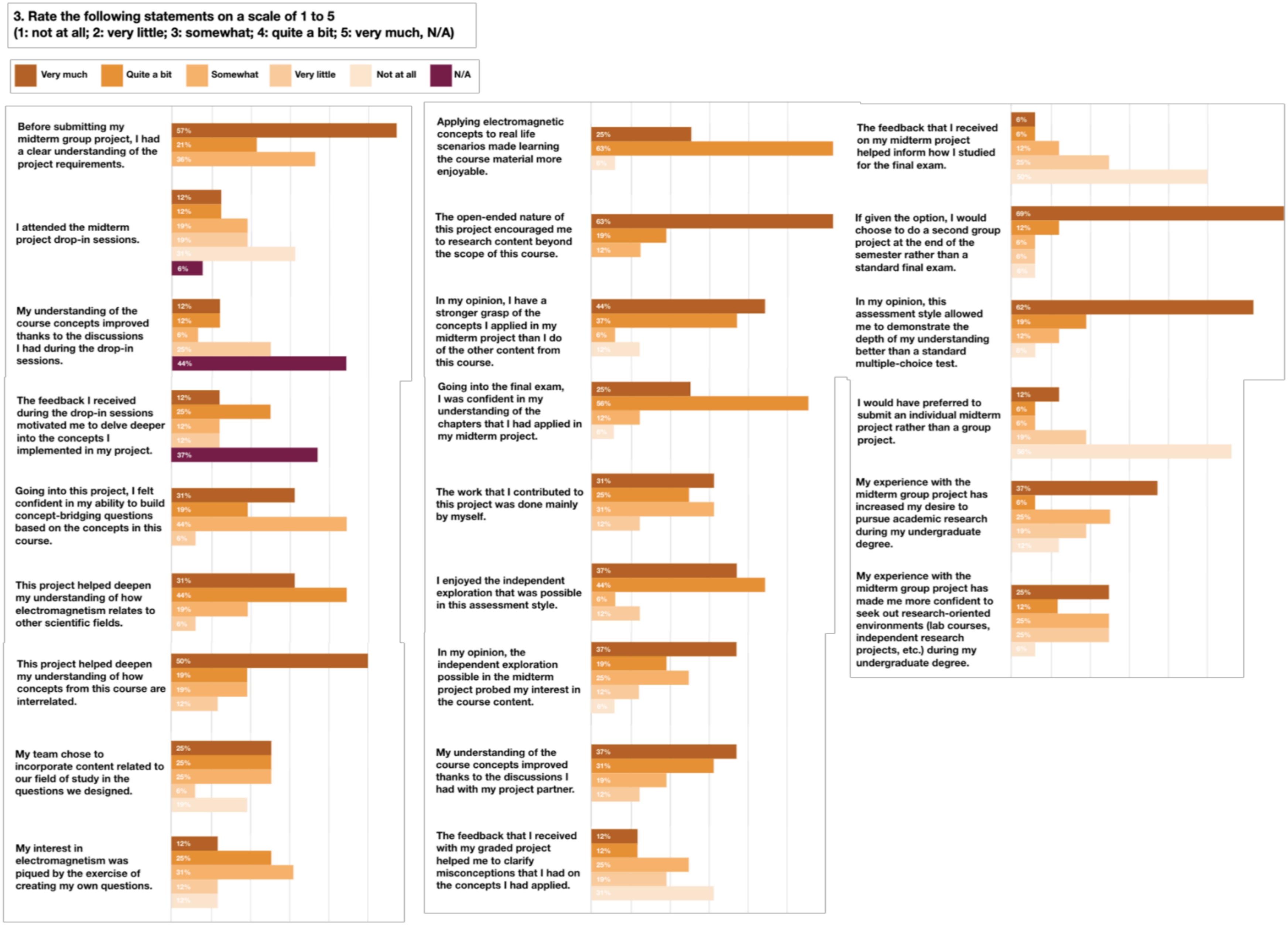


Table 7

Learning Benefits of Each Assessment Style Outlined By Midterm Project Students

Learning Benefits of Each Assessment Style Outlined By Midterm Project Students	
Midterm Test	**Midterm Project**
	Better demonstration of understanding through the creation of problems
	Increased understanding of and curiosity In course content
	Student chooses what they're being evaluated on
	Relieves stress
	Students can set the pace of their learning
	Students have time to explore the content on their own

Table 8

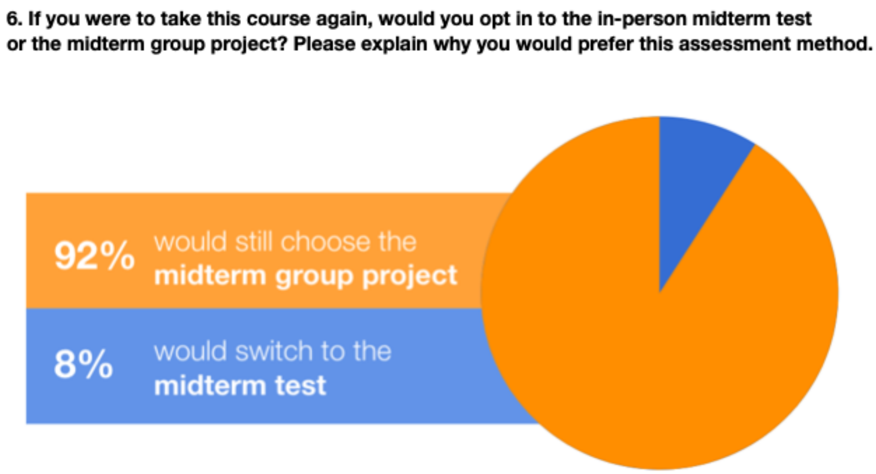
Learning Disadvantages of Each Assessment Style Outlined By Midterm Project Students

Learning Disadvantages of Each Assessment Style Outlined By Midterm Project Students	
Midterm Test	**Midterm Project**
Does not allow in-depth demonstration of a student's understanding/process	Difficulties of collaborative work
Limited to content chosen by instructor	Less comprehensive in scope—sacrifices breadth for depth—students can ignore certain content

Once again, this second group were asked whether, if they were to take the course over again, they would choose the midterm group project and 92% of these respondents answered that they would (as seen in the next figure). This percentage shows a considerable increase in their preferred assessment style as compared to the previous group.

Figure 7

Survey Question 3 to Group Project Students



These students went on to describe the reasons why they would stick to the midterm group project (as seen in Table 8). They noted increased confidence in their ability to apply the course content as an effect of their experience with the concept-bridging project, that they found the research involved in the assessment to have been enjoyable, that they benefitted from the longer timeframe to demonstrate their work, all of which alleviated the stress they felt towards being evaluated as compared to a test. Furthermore, the students cited having an increased level of curiosity in the course content and having appreciated their ability to creatively apply electricity and magnetism, subjects that they were often not that interested in, to real world applications that they were eager to learn more about. One student expressed that having to build concept-bridging problems was a good way to verify her understanding of the course content: "I really like the challenge of having to come up with my own questions, it is a very good way to evaluate one's knowledge of the material." Another student mentioned that the research required for the project was a more enjoyable way to engage with electromagnetism concepts: "I found it a lot easier to sit down and research for a project for 5 hours than to sit down and do a bunch of practice problems for the midterm for 5 hours." The project students also recognized that there had been a higher degree of leniency in the marking of their midterm assessment. From these students, only one said that they would switch to the multiple-choice because they felt more comfortable with test taking.

At the end of the survey, students were asked for any final aspects of their experience in the course to share that had not been addressed by the survey questions. In response to this question, students reiterated the value of application-based and exploratory learning but emphasized that there was a need for increased grader feedback on the midterm project. One student also said that the scientific inquiry and collaborative aspects of the course made it feel more like a lab course than a lecture-based course.

By bifurcating the survey between the students who opted in to the midterm test and those who opted in to the midterm group project, I was able to get a clearer understanding of the similarities and differences between the two student cohorts. What we notice from these survey findings is that, even if they are both able to articulate similar benefits and disadvantages of the contrasting assessment styles, there remains a clear preference amongst each group of students for their chosen midterm assessment. Considering that this survey was taken at the end of the semester, once students had received their final grade in the course, it is interesting to recognize that the students who took the test generally report that they would stick to the test, and the project students would stick to the project. This goes to show that, students are not easily swayed in their decisions to navigate a course. Even students who reported, in their own words, that the project provides for a deeper level of understanding of the course concepts, stand firm in their choice of the test because of issues related to the investment of time and effort.

At the beginning of the survey, students were asked if they would consent to a follow-up interview with myself and an undergraduate TEAM mentor, Peter El Khoury, to address many of the same interview questions more in depth. Of the 34 survey respondents, 8 students agreed to participate in these recorded interviews. The following section provides a detailed account of my analysis of these interviews. The questions covered in the interviews can be found in Appendix E.

Table 8

Reasons Reported By Group Project Students for Sticking to the Midterm Group Project

Reasons Reported by Group Project Students for Sticking to the Midterm Group Project		
Confidence in ability to apply course content	"I would like to do another project now that I feel more confident in my ability to produce a reliable/ verifiable answer after having done the first midterm group project."	"I feel more confident with demonstrating my knowledge on the project."
Found research enjoyable	"I found it a lot easier to sit down and research for. a project for 5 hours than to sit down and do a bunch of practice problems for the midterm for 5 hours."	"Research was very interesting, loved what I learned through it."
Longer timeframe	"[T]here was more time to work on it (we had until after the break as opposed to the multiple choice midterm that was before reading week)."	"Having a longer period of time to work on it reduced stress a lot."
Reduced stress compared to test	"i don't do well with exams because I get really anxious and am a slow worker so I prefer to take my time."	"I have extreme anxiety that causes the days leading up to an exam (and the day itself) to be almost unbearable."
Creative application of real world concepts	"[I]ts more like a real world situation we would be in."	"I really liked the aspect of creativity and real-word applications and it inspired me to delve deeper to broaden my knowledge."
Building concept-bridging questions was a better demonstration of understanding	"It allowed for so much more freedom in how I could demonstrate my understanding."	"I really like the challenge of having to come up with my own questions, it is a very good way to evaluate one's knowledge of the material."
Grade optimization due to increased grading leniency of the project	"[M]ostly because the grades received were a lot higher than those received on the test. Most students are in this course to get as high of a mark as they can and never touch physics again, and the project definitely works towards that goal. Had I taken the midterm test, I would not have done as well in this course from a numbers perspective."	
Collaborative nature of the project	"We could talk through topics and collaborate."	
Increased student's curiosity in the course content	"I find it a lot more interesting than an exam. It made me more curious about certain concepts of the course and helped me learn a lot more and in a more enjoyable way."	
Provided greater flexibility	"Amidst other midterms the porject is a blessing since it is so much more flexible."	

Student Interviews

The interviews conducted in this study were an important complement to the student survey, which, although it allowed me to distinguish trends between the two student cohorts, revealed very little about what preconceived ideas and preferences went into each student's choice of how to navigate the course' personalized assessment scheme. The interview profiles in this section reveal personal accounts from eight students as to why they chose to navigate the course in the way they did and the many foreseeable and unforeseeable impacts their decisions had on their understanding and appreciation of the course content as well as their own learning styles. Each profile includes my analysis of the main ideas expressed by the student accompanied by a table with a more detailed account of key excerpts from their interview transcript.

Midterm Test Student 1

This interview shows a student who strongly believes that tests provide her with the ability to engage with and apply her understanding of the course content. She thrives in an environment where she can work through problems with her peers, though she strongly prefers to demonstrate her understanding on her own. It is also worth noting that, at the time when this interview took place, she was doing a summer research internship because she found that she really liked to delve into the application of the concepts she was learning. We see a student whose deepest concern is her mastery of the course content. What motivates her more than anything is being able to get to the correct answer on her own, which played into her choice of the midterm test.

> I feel like individual work motivates me to be certain that I personally understand it for myself and I wouldn't be really relying on others for their knowledge to help boost my own mark, if that makes sense. I get that group projects are great for bouncing ideas off of each other but there's a time where I need to be able to explain this thoroughly and understand it for myself.

When given the choice, she prefers to demonstrate her understanding on individually graded assessments because she feels that they are a more honest reflection of her knowledge. She chose the midterm test because it allowed her to demonstrate the breadth and depth of her knowledge rather than honing in on only select concepts. However, her choice was also motivated by the shorter timeframe of the test rather than an open-ended project which fewer set guidelines.

> I liked that a project would allow me to do my own research and be a little bit more creative with it. But I feel like a project would also be a lot more difficult to navigate. Because I want to, like,

> go over and beyond. Because I want to make sure that I'm doing my absolute best. And, because there's no clear cap on that, there's no right answer for a project, right? I just keep going and going and going and going and going until I run out of time.

Although she acknowledged that she was reluctant to being assessed in a way that invited uncertainty into the grading scheme, she also shared that she was interested in exploring applications of the course content. She particularly appreciated that the professor included real life biology-related applications of the course content into the lectures. The personalized learning grading scheme allowed her to engage with the course content in a variety of ways that helped her learning. Access to peer mentors who took the time to walk her through problems was particularly impactful.

> I remember going to some of the the [mentorship] sessions, in particular, one session stands out to me, which is when there's like that bonus question […] which I could not solve on my own. I went to that session and [the mentor] stayed there for I think two hours with me to to draw diagrams and figure out the process. In the end, I was able to understand it and even explain it to some my other friends who want to solve it as well and that was very satisfying.

In fact, the tutorials had such a big impact on her that she decided to play the role of mentor in the following semester. Ultimately, this student notes that the ability to opt into different elements of the course allowed her and her peers to have a better understanding of their own learning styles.

> I think it makes us feel more flexible and like free so that we're not super confined to one specific learning model. Because I'm motivated to participate in as much as I can. I know that I have friends who definitely do a lot better just doing the reading, or just going to tutorials, because they don't absorb as much from the reading as I think I do or they don't gain as much from interacting with other people as I do so they prefer to take that time and instead spend it on themselves, doing extra practice problems on their own. Because I feel like we each know our learning style best.

Because going through the pre-lecture readings in the context of this course was beneficial to her understanding, she had decided to use it as an approach to her learning in other courses. In sum, the course enhanced her curiosity in and understanding of electricity and magnetism.

Table 9 displays direct excerpts from this interview in order to provide the reader with a broader understanding of the student's perspective.

Table 9

Midterm Test Student 1 Interview Excerpts

Midterm Test Student 1 Interview Excerpts	
Theme	**Interview Excerpt**
Motivated to learn individually	"I feel like individual work motivates me to like be certain that I personally understand it for myself. And I wouldn't be really relying on others for their knowledge to help boost my own mark, if that makes sense. I get that group projects are great for like bouncing ideas off of each other. But there's a time where I need to be able to explain this thoroughly and understand it for myself. And the only way I see that I could do that is if it is individual. Otherwise, I'm sure that I would be discussing with everybody in my group and trying to get to an answer altogether."
Preference towards being graded individually	"I don't like the idea of a large chunk of my grade relying on my ability to to work with other people. Because while that's a really important skill, I want to be able to achieve my mark, mostly depending on my own knowledge, and my own work, and then working with a group that's more experience and soft social skills."
Wanted to be evaluated on full breadth of course content	"[T]he way that it tested my knowledge wasn't the way I wanted, personally, to be tested on because the midterm project seemed like I'd pick one or two concepts and go really into detail, which is fantastic like that. That's really interesting to really deepen my understanding. However, for the midterm test, I felt like I was more encouraged to get an understanding of everything in general. And then I could demonstrate that all at once. […] I went with the one that I felt I could better demonstrate my knowledge on."
Preferred to not have to deal with open-ended nature of project	"I liked that a project would allow me to do my own research and be a little bit more creative with it. But I feel like a project would also be a lot more difficult to navigate. Because I want to go over and beyond. Because I want to make sure that I'm doing my absolute best. And, because there's no clear cap on that, there's no right answer for a project, right? I just keep going and going and going and going and going until I run out of time."
Likes creative application but more concerned with grade-optimization	"Because I value my grades specifically for the course, I was more inclined to focus on the stuff I knew was gonna get tested on. But for myself, I would love to have the opportunity to really take these concepts and apply them more creatively. I think I mentioned, the project does interest me very much. But because I knew I'd probably do better with the exam, I decided to go with that."
Enjoyed engaging with professor and seeing real-life applications in lectures	"I also really liked how he brings in real life examples. And I think, specifically, there was the generator that he presented in magnetism. That was really, really cool to me. And I think I stayed after class with him, just to discuss it, because it didn't quite click during class. And the fact that he stayed after class for, I think, maybe 10 minutes, at least, to really discuss all of our questions with us, and make sure that we understand it, and in fact, encouraged us to go to his office hours so that we can discuss it further. That made it really fun for me."
Value of engaging with mentors during tutorials	"[T]he [peer mentoring] sessions where we had this other help, and this other practice, that was really interactive, and the people chosen to guide those, I feel like they were perfectly chosen. Because the degree to which they helped me I feel is astronomical. So yeah, just participating in everything being enthusiastic. […] I remember going to some of the the [mentorship] sessions, in particular, one session stands out to me, which is when there's like that bonus question, and I think the last CAPA, which I could not solve on my own, and I went to that session and [the mentor] stayed there for I think two hours with me to to draw diagrams and figure out the process. And in the end, I was able to understand it and even explain it to some my other friends who want to solve it as well. And that was very satisfying."
Flexible grading scheme helped too understand learning style	"I think it makes us feel more flexible and free so that we're not super confined to one specific learning model. Because, well, I'm motivated to participate in as much as I can. I know that I have friends who definitely do a lot better just doing the reading, or just going to tutorials, because they don't absorb as much from the reading as I think I do. Or they don't gain as much from interacting with other people as I do. So they prefer to take that time and instead spend it on themselves doing extra practice problems on their own. Because I feel like we each know our learning style best, so being able to pick and choose means that we can choose the learning style best for our success."
Exposure to pre-lecture reading was beneficial to learning	"I realized that even though reading the textbook doesn't sound fantastic, I now know that it definitely helps me a lot seeing the concepts beforehand. And that motivates me to put in the effort and the time to really go through understand and annotate. So in other courses like biology where a textbook isn't required, I felt motivated to go research the topics before we discuss them in class or to at least read through lecture notes before going to the class."
Professor's approach encourages curiosity	"I think the way that [the professor] presents the course, he really encourages us to not only learn the concepts, but also bring them into ourselves and see them in our everyday lives. And so that kind of curiosity that he kindles definitely makes me more curious and want to do research overall."

Midterm Test Student 2

This interview shows a student who was not intrinsically motivated by the course but found that a flexible grading scheme provided her with ample opportunities to engage with the material. Although she is very clear that she wants to develop her abilities to apply the course content in creative ways, she still opted for a midterm assessment style that she felt she could do well on. At the end of the semester, the personalized weighting scheme, with its many options to collect points from the different course components, also helped her do well in the course despite getting sick during the final exam period. We see a student who was not naturally inclined to understanding physics concepts but has a history of investing a lot of work into the material. Her academic goal is to get into medicine and appreciates the need to develop her problem-solving skills (Table 10). A big part of her choice of university was gaining access to undergraduate research opportunities. She is adamant that, although she is more confident in her ability to memorize material than apply concepts, there is more value in applying concepts in order to understand them.

> [S]ome of the stuff that is just memorized I'm able to easily retain but I would definitely say the stuff that I'm able to better explain and like actually understand is stuff that I've done an analysis of, critically thought about it. Because, just like problem-solving, analysis allows you to get a more in depth look, in general. And I think it allows you learning. I think it's more about understanding than just memorizing. And oftentimes, when people memorize things, they don't necessarily understand them. And so I think that problem solving is really an important step in being able to understand the concepts, which is obviously desirable.

However, she still chose to do the midterm test because she feels more confident in her ability to memorize concepts rather than apply them. What drew her to the test option was that it provided a more familiar and comfortable avenue to demonstrate her understanding.

> I understand how the midterm project was probably like a really good option for some people. But, personally, I think I'm just more comfortable writing tests. And I knew what to expect at least with that.

She also noted a clear preference for the short timeframe of a test versus a project. Although she recognizes that some students struggle with multiple-choice tests, she shared her personal strategy to answering multiple-choice style questions. It was the finite nature of this assessment style, both in timeframe and ability to narrow-in on one correct answer that stood out to her as the main reasons to choose the test. However, she also clearly states that tests, though the standard in the formal education system, reinforce memorization and, therefore, are not a sufficient measure of understanding.

> I think that's a really big problem, actually, with the way the education system is up until like grade 12 or whatever. And luckily, I did an IB Diploma so I have a little bit of experience with more problem-solving questions, like taking concepts and applying them as opposed to just memorizing and regurgitating information. But memorizing and regurgitating information is what I'm really good at.

Despite this, she admits to her own reticence in having to create her own concept-bridging problems. This course was her first exposure to electromagnetism content and the personalized learning assessment scheme helped her to stay accountable to engaging with the material on a regular basis.

> I really like having something to do continually throughout the semester, just to make sure I'm understanding as we go along. So it's nice just to have something every week to continue working on because I know [in] some of my other classes, it was midterm and final or a scattered test. So at least when it's every week, you can continually assess your understanding.

She chose to opt out of the pre-lecture readings because she didn't like the way the Perusall system's learning algorithm attributed points but says she still decided to do them for no marks because they contributed to her learning. She also found significant value in being able to work through challenging problems with mentors and peers in the tutorials.

> I found it more helpful just to have someone to work through the problems with like, especially if I was stuck, because I know a lot of the problems that we did in tutorials were more challenging problems, specifically that I might not have been able to solve on my own.

Finally, she found that the structure of the lab courses provided her with sufficient time to think and explore the concepts before being tested on them. Table 10 displays direct excerpts from this interview that bring to life my summarized account.

Table 10

Midterm Test Student 2 Interview Excerpts

Midterm Test Student 2 Interview Excerpts	
Theme	**Interview Excerpt**
Struggles with physics	"[F]or me, physics is my hardest class. I don't like it particularly and it's something that I struggled with. So I was in grade 10 and I worked hardest at this class. And it actually ended up being my best grade. So I think going into [this class], just like having that idea that I wasn't good at physics made me want to study harder and do better."
Values problem-solving abilities	"I want to go into into medicine eventually. And so obviously, problem solving, being able to see multiple sort of things and then put them together and arrive at a conclusion. That's impressive. So definitely, I think it's an important skill."
Thinks understanding through problem solving is more valuable than memorization	"[S]ome of the stuff that is just memorized I'm able to easily retain but I would definitely say the stuff that I'm able to better explain and actually understand is stuff that I've done an analysis of, critically thought about it. Because, just like problem solving, analysis allows you to get a more in depth look, in general. And I think it allows you learning. I think it's more about understanding than just memorizing. And, oftentimes, when people memorize things, they don't necessarily understand them. And so I think that problem solving is really an important step in being able to understand the concepts, which is obviously desirable."
Confident in ability to memorize for a test but does not retain long term	"I know a lot of people get anxious about writing tests and exams but I've never been a person that's really super anxious about writing exam or worried about finishing in time or that type of thing. I have a fairly good memory. And so I think the project is a good option for people who want to be able to explain the concepts using their notes and everything and having access to that information. But I don't necessarily. I'm okay at memorizing and retaining information. So it's a little bit trickier once, obviously, post secondary level, and it's more becoming problem solving questions. But, you know, I'm still leaning towards test just because it's something I'm more familiar with."
Comfortable and familiar with test format	"I understand how the midterm project was probably like a really good option for some people. But, personally, I think I'm just more comfortable writing tests. And I knew what to expect at least with that."
Preferred short test timeframe	"[I]t had a date and time and so I could just study for it and then do it. It wasn't like I had to work on it for a long time and keep adding things like that and stuff with a project, which, there's nothing wrong with that but again, it's just a personal preference."
Multiple choice provides finite answers	"My strategy, when I do multiple choice is [to] do the question before looking at any of the answers, and then answer. I think that's really helpful. Because usually it reinforces that I actually understand what I'm doing and that I was able to arrive at an answer. Because sometimes, in long answer problems, you know, you can get halfway through the question, and then not really be sure of where to go next. And so you're unable to arrive at a final answer. But at least with multiple choice, in some cases, I feel like, if you make it to almost the end of the problem you can then go to the answers and see which one kind of fits best if you're not sure."
Recognizes ability to memorize and regurgitate information but critical of this approach for learning	"I think that's like a really big problem, actually, with the way the education system is up until like grade 12 or whatever. And luckily, I did an IB Diploma so I have a little bit of experience with more problem solving questions, taking concepts and applying them as opposed to just memorizing and regurgitating information. But memorizing and regurgitating information is what I'm really good at. So, it's definitely like a bit more of a challenge and something I'm still getting used to. But I recognize how that's like really important. Memorizing information doesn't really do anything for you and that's not the point of science."
Prefers to be evaluated on pre-prepared questions	"I thought it would be difficult if I had chosen to do the project to find sort of an idea that combined all the chapters that we had covered so far, and I wasn't sure that I would be able to adequately demonstrate my understanding of each concept in one project. But I think that's also just more like how my brain kind of works. I'm not a super project deep person. And so I just felt that at least with the midterm, I didn't have to worry about covering every subject that we had looked at so far. And the the questions were already there and I just had to answer them. I didn't have to come up with questions and answer them if that makes sense."
Regular accountability through course components benefitted learning	"I really like having something to do continually throughout the semester, just to make sure I'm understanding as we go along. So it's nice just to have something every week to continue working on because I know [in] some of my other classes, it was midterm and final or a scattered test. So at least when it's every week, you can continually assess your understanding. And have a better idea of which specific parts are more difficult for you to understand versus what you're already good at."
Doing readings before class helped learning	"[I]t's like the reverse classroom where you do a little bit of reading first, practice questions, and then come in and what you're learning in the lectures is sort of just reinforcing and going a little bit more in detail. I found that definitely really helpful because it sort of forced me to keep up with the readings so that I wasn't totally lost in class. But it also sort of nurtured a bit more of an independence in learning."
Collaborative problem solving benefitted learning	"I found it more helpful just to have someone to work through the problems with, especially if I was stuck, because I know a lot of the problems that we did in tutorials were more challenging problems, specifically that I might not have been able to solve on my own."
Inquiry-based lab structure was beneficial to conceptual understanding	"I really liked how he had the labs A and B. So the first one was a little bit more just to get more familiar with sort of the setup and what we would actually be doing and how to use the equipment. And then just having a more casual discussion with the TAs and then the Lab B would be actually where we had to do a report, but we were coming in and we already knew how to use the equipment and kind of what to expect even though we were designing our own methodology. So I really liked that aspect of it. And overall, I think it definitely enhanced the conceptual part of the course."

Midterm Test Student 3

This interview shows a student who was confident in his understanding of the course content from the get go. His stated aim was to maximize his grade in the most efficient way, which the test allowed him to do (Table 11). We find a student whose decision to take the midterm test was purely strategic because he came into the course with a strong background in electromagnetism from exposure during high school where he had chosen to specialize in physics.

> I was familiar with the course content before so I didn't feel like I had to do this course very hard. So, what I was trying to do is maximizing a GPA and and also minimizing my time on the course but also got some interaction with other students and mentors.

The opportunity to opt into his preferred assessment style only reinforced his desire to choose the most efficient manner of navigating the course.

> [B]eing shown a lot of choices in terms of how I got evaluated does make me think about to how best to take the course to maximize my grades. Sorry, for being realistic. But I don't think it caused me to think a lot on which way is best for me to learn.

The test offered him a chance to demonstrate his understanding in the least time-consuming way. Despite being intent on pursuing research opportunities during his undergraduate degree, he wanted to focus his research on content related to his program, Economics and Computer Science. However, he notes that his favorite part of the course were the labs because of their more hands-on nature. "I think it's the fact that it's not doing physics on paper."

He also describes the tutorials as having been valuable to support his learning, principally because they provided him with an opportunity to understand another person's way into a problem.

> [T]he solutions from the team mentors were more in depth, like exposure to problems, and then in depth solutions that are being solved and you're getting the full solution. That's that was what was beneficial.

Despite their noted value, he still felt that students were reluctant to engage. Table 11 displays direct excerpts from this interview in order to let the student speak for himself.

Table 11

Midterm Test Student 3 Interview Excerpts

Midterm Test Student 3 Interview Excerpts	
Theme	**Interview Excerpt**
Decision for test was based on maximizing grades and minimizing investment	“I was familiar with the course content before so I didn't feel like I had to do this course very hard. So, what I was trying to do is maximizing a GPA and and also minimizing my time on the course but also got some interaction with other students and mentors.”
Personalized assessment schemed allowed for grade maximization	“[B]eing shown a lot of choices in terms of how I got evaluated does make me think about to how best to take the course to maximize my grades. Sorry, for being realistic. But I don't think it caused me to think a lot on which way is best for me to learn.”
Preferred short timeframe of test	“I took the test, because it's just a quick way for me to get evaluated. Taking the test is just three hours of sitting at the test. Compared to that, taking the group project, I had to do some logistics, like finding my partner, then struggling through the idea of the project, and then doing it. So, to me, it's just a lot of time. More time and effort to do the project compared to just sit.”
Enjoys labs because more applied learning	“I think it's the fact that it's not doing physics on paper.”
Tutorials allowed for more in-depth explanations from mentors	“[T]he solutions from the team mentors were more in depth exposure to problems, and then in depth solutions that are being solved and you're getting the full solution. That's that was what was beneficial.”
Would have preferred more active participation in tutorials	“[T]he tutorials, they're great, because you've tried to make students interact with each other a lot. But somehow, in my opinion, between the students in the tutorial there's a limited shyness between people. So I mean, you've done a lot of effort to make people less shy, but somehow, it still happened.”

Midterm Test Student 4

This interview shows a student whose goals were set on maintaining high grades in her undergraduate courses in order to open doors for her studies down the line. Although she expressed interest in research, her focus on optimizing for grades meant that she was strongly opposed to engaging with a project-based midterm assessment (Table 12). We find a freshman student with her sights set on honors biology. Coming into the course, she had little interest in the physics content and was highly motivated to get the best grade that she could for the lowest investment of time and effort. As a freshman student, she articulated that she’s still adjusting to the university-level workload and has no extra time or energy to devote to a course she views simply as a requirement for her program.

> I didn't have the energy to devote to making the absolute best of my physics experience, I just sort of had to do well enough, like engage, like, do what was within my capability, like engage in class do all the work. I didn't really have it in me to go the extra mile and beyond and do the stuff that seemed more difficult, but I kind of knew would maybe be a little better.

Despite recognizing the value of a project-style assessment, her chief concern was getting a good grade in the course. She viewed the test as the most straight-forward way for her to accomplish this. Between the choice of a sit down test and a multi-week project, her decision was based on maximizing her time. Another factor that played into her decision was her confidence in her test-taking abilities.

> I'm pretty good on tests, I did well on the midterm test. And having made that choice, I would have made it again a million times. I know a lot of people don't like midterm tests. And I understand that you sort of you don't really connect with the material as much as on a project. But for me, I wasn't really worried about connecting material, I wanted to optimize my grade, and spend the least time stressing about it.

Yet despite her proficiency with tests, she recognizes that they promote a manner of learning the course content that is geared towards the exam. This student also admits that her approach to test-taking strongly resembles the 'plug-and-chug' method.

> I do find the just apply the formula questions easier because it's like, Oh, I know how to do this. Like you take a word problem. You're like, oh, I need to do this. This this. I find that easier. Sometimes the conceptual questions like, Oh, we didn't learn this in class. This is a difficult concept to apply. But I do think that that's probably better for my learning, because it makes me think more critically about the concepts and like, it actually makes me use my brain rather than boop boop boop plugging into a formula.

Another significant reason why she opted for the midterm test was because she was strongly opposed to working in teams. Although she recognizes that there is value to collaborative work, her preference is still to be graded on her own.

> [A]s much as I don't like it, I know that it improves my learning to help to explain concepts to other people. I hate it. But I know it's good for me, because it forces me to think about the concepts more deeply.

In fact, she notes that, if it weren't for the lab and tutorial portions of the course, she would not have interacted with any of her classmates. In the context of this course, because she could choose to opt out of the group project, she took the option that would allow her the most independence. "I understand that collaboration is important. But since I was given the option not to do that, I figured that's a skill that I would own at another time."

This student acknowledged that she chose this university specifically for its research opportunities. However, in the context of this prerequisite physics course, because her primary focus was optimizing her experience for the sake of her grades, she expressed concern for the level of grader-subjectivity on open-ended projects. Furthermore, her success in the midterm test offered her a higher degree of confidence going into the final exam. In terms of the course structure, she noted that the ability to opt into different elements of the course enhanced her engagement with the course content, mainly because it provided her with multiple avenues to test her understanding and accumulate points.

> I knew that I had to opt into as many options as I could. Because of this, once again, this is marks driven, I knew that I would be able to sort of rack up marks on the easy things, although it would be more work. This was like within my capability of okay, I can put this much effort in. And I know that that'll improve my mark. And I found that that was a good way to sort of trick students into doing more work of like, oh, here, it gets some easy marks by actually learning the content […].

In all, the personalized learning assessment scheme reinforced her sense of accountability over her work. Table 12 displays direct excerpts from this interview to further flesh out this student's perspective.

These four interviews with the students who opted for the in-person test show a variety of reasons why students in this course who are interested in pursuing research further on in their academic careers are reticent to engage in a project-based assessment in this course. We see that grades play a crucial role because they help these students secure future opportunities for more unconstrained learning. However, the other more important factor, which goes hand in hand with grades is students' perception of time. Many of these students were looking for the most efficient way of engaging with the course. Even if they were able to identity compelling reasons that creating concept-bridging questions might satisfy their learning more than preparing for a multiple-choice test, it is the anticipated duration of time to invest in the inchoate elements of working towards a less-defined goal that turn these students off the foreseeable value.

Table 12

Midterm Test Student 4 Interview Excerpts

Midterm Test Student 4 Interview Excerpts	
Theme	**Interview Excerpt**
Could not devote any extra effort in course	"I didn't have the energy to devote to making the absolute best of my physics experience, I just sort of had to do well enough, engage, do what was within my capability, engage in class, do all the work. I didn't really have it in me to go the extra mile and beyond and do the stuff that seemed more difficult, but I kind of knew would maybe be a little better."
Preferred short timeframe of test	"I understand that working on it over a couple of weeks will probably get you to think about the concepts more deeply. But quite frankly, I just thought to myself, I don't have the time for this, I'm doing the midterm test, I didn't want to spend weeks on it. I didn't want to be worrying about it for weeks, I found it way less stressful to just do a test."
Preferred test in order to optimize grade	"I'm pretty good on tests, I did well on the midterm test. And having made that choice, I would have made it again a million times. I know a lot of people don't like midterm tests. I understand that you sort of you don't really connect with the material as much as on a project. But for me, I wasn't really worried about connecting material, I wanted to optimize my grade and spend the least time stressing about it."
Learning for the test does not allow for long-term concept retention	"[Y]ou just think about it quickly and then you forget it. You do a test that you can't even remember what the questions were. I don't remember what formulas to use by the time the exam rolls around. You have to relearn it all. I imagine that with the project, you'd probably be getting really into one subject, perhaps even thinking about it, critically connecting it to ther topics, which does seem good. But I just personally chose the midterm project because it was easier for me."
Understands that applying concepts is more beneficial to learning than plug-and-chug method	"I do find the just apply the formula questions easier because it's like, "Oh, I know how to do this." You take a word problem. You're like, oh, I need to do this, this, this. I find that easier. Sometimes the conceptual questions are like, "Oh, we didn't learn this in class. This is a difficult concept to apply." But I do think that that's probably better for my learning, because it makes me think more critically about the concepts and it actually makes me use my brain rather than boop boop boop plugging into a formula."
Had no interest in project	"[F]rom the first moment, I heard that there was midterm product versus test I'm like, that's it. There's no way I'm doing a group project. I'm not even thinking about it. So I didn't really address the requirements that much. I just hate group work, unfortunately." "I just find that working with other people on projects makes it slower and more difficult."
Prefers to work individually	"[A]s much as I don't like it, I know that it improves my learning to help to explain concepts to other people. I hate it. But I know it's good for me, because it forces me to think about the concepts more deeply."
Engaged in course alone	"I don't think I ever spoke to a single person in the class. Except my lab mates who I had to speak to for labs. I did this course alone."
Prefers to put off collaboration	"I understand that collaboration is important. But since I was given the option not to do that, I figured that's a skill that I would hone at another time."
Felt confident for final exam thanks to midterm test result	"My success on the midterm really gave me confidence. […] I felt pretty confident going into the final, I maybe could have studied a little harder, but it was the end of semester, I was dead already. And I'm happy with my result."
Flexible grading scheme allowed to maximize grade	"I knew that I had to opt into as many options as I could. Because of this, once again, this is marks driven, I knew that I would be able to sort of rack up marks on the easy things, although it would be more work. This was like within my capability of okay, I can put this much effort in. And I know that that'll improve my mark. And I found that that was a good way to sort of trick students into doing more work of like, "oh, here, it gets some easy marks by actually learning the content." I found that really helpful. And I appreciated the effect that it had on my grades. I really enjoyed the opt in system."
Course components provided beneficial accountability	"[T]hat's kind of something I sort of came into the course knowing but that more just confirmed. It's like, okay, I need that accountability to get stuff done. Okay. It's really helpful."

The following descriptions and tables provide an overview of the main learnings from the four interviews conducted with students who opted in to the midterm group project.

Midterm Group Project Student 1

This interview shows a student who feels that her investment in the midterm project had a significant impact on her appreciation of physics. By engaging thoroughly in all the different aspects of the course, she was able to develop a clearer sense of her own learning style and enjoy a course that she had originally seen as little more than a program requirement. We see a student who, when presented with the option of choosing a project-based assessment style, knew that it would be most beneficial to her learning (Table 13). Even though she wasn't particularly interested in the course content, she knew from the get-go that the project was a chance to relate electromagnetic content to applications that she was interested in.

> I'm trying to do neuroscience next year for my program, and my partner is transferring into physiology and so both of us are very interested in the physics of the body or the physics of how things work in the brain. […] [W]e basically were just smart about picking something that actually seemed interesting to us. And that helped us really engage with the course content because, at the end of the day, when it's something that's applicable to a topic that you care about, it makes it more interesting.

Although she recognizes that the project would present a challenge because there were fewer directions and constraints to work within, she had a clear understanding of the learning potential of a project. Though her friends and even her project partner were uneasy about the project's open-ended nature, she felt the project rubric was clear enough for her to be confident that she would be able to adequate demonstrate her understanding. That said, she and her partner did run into an issue with their calculations and were relieved to hear from a mentor that she could still present her findings within the parameters of the project.

> [T]he point that was made to us in the dropping session was that it's okay if that doesn't quite work out. It's not necessarily about finding a calculated value that is exactly correct. But it's about, doing the math and seeing how things might work together to come to an answer, even if it may not be the right answer. And so that kind of thinking was how we tried to not get stressed.

However, knowing that projects were a better way for her to approach the course content, she originally intended on doing the test because of the perceived effort involved in a group project.

This investment ended up paying dividends in both her grade in the course and her understanding of the course content.

> [It] ended up working out for me because I definitely would have done much worse on the exam than I did on the project. So from a grades perspective, it was a good call. But I also think that I definitely had to do more work to understand the content for the project, which was good, probably for my overall understanding of physics.

She notes that the flexible grading scheme was so forgiving that she had almost no pressure going into the final exam.

> [J]ust purely from a grades perspective my stress dropped significantly once we got the midterm project back because I was looking at needing, like a 70 on the exam to when I got the project back, I needed a 45 for an A.

In fact, because she had accumulated such a high grade going into the final exam, she recognizes that she invested a lot less effort learning the content in the second hall of the semester. The project-based assessment style allowed her to take a slower, more intuitive approach to learning the course content that was more aligned with her perceived learning style.

> [T]he ability to pace yourself and do it on your own time. I look at something, I sleep on it, I think about a little bit and then I go back to it. Especially with physics, that's how I am able to problem solve. And so having the ability to not be in an exam situation where I have two hours to answer all the questions and like, I need to know, and if I don't, I don't have the ability to take a couple of days, even like a week and really think about, ‘okay, now that I know what I'm going to try to do for this project, what can I do?’ What are the resources available to me and just working through making a good plan, like that ability. Even just that is huge as an advantage personally, as a learner. That's how I learn.

Furthermore, understanding her partner’s approach to thinking through the concepts had a significant impact on her own understanding.

> [My partner] and I think very differently and have a different approach to things. And so the ability to bounce ideas off of each other, do the math together, and make sure we're not making silly math mistakes. All of that also really helped me when, let's say, I'm going to do a final exam—‘Okay, I remember, I got this wrong when we were working through it. This is why it was wrong. Cool, I won't do that, again.’

However, more than anything, it was the ability to engage in open-ended exploratory research that this student felt was most useful to her ability to think and learn new concepts although she would have appreciated more conceptual feedback from the graders. Her main takeaway from the flexible course structure was that it alleviated much of the stress of a prerequisite physics course. Table 13 displays direct excerpts from this interview in the students' own words.

Midterm Group Project Student 2

This interview shows a student who prefers to sacrifice breadth of knowledge for depth. He is not only concerned with the discrete information presented in the course but also with developing his own abilities to apply that knowledge in creative ways (Table 14). We see a student who is interested in the process of learning and tapping into his own sense of curiosity. Even though this course is a prerequisite, he wants to relate the course content to their interest in biology in a way that is creatively and intellectually stimulating. He initially found the unconstrained nature of the project to be so open-ended that it was hard to know how to approach it.

> [B]ecause it was so open ended it was really easy to find ourselves in very difficult equations and concepts that we didn't know how to simplify or work with. And it was the hardest part of the project for us was walking the line between making it not so straightforward and making, you know, connecting concepts, deriving equations, but also not going too far to the point where we have no idea what we're talking about and we're, what's the expression, biting more than we can chew.

Although he suggested that future iterations of the assignment could use more guardrails, he found that the opportunity to set up his own research parameters to be an invaluable part of the learning process. Ultimately, although grades were a concern for him, it was showing a demonstration of his creative investment that was the most rewarding part of the whole process. In fact, the pedagogical exposure also influenced his personal desire to pursue both research and teaching.

> [S]eeing my grade for the midterm was so much more rewarding than any other grade I've gotten even grades that were higher than that because it was just a validation of the skills that I thought I had. Whereas tests, if I do well, I kind of feel like I got lucky in the questions I studied or the way I studied having worked out. But this project was a direct result of a lot of thought and time and the way I wrote everything out and the way we

> went about structuring it and the research. It just felt more personal. […] Even now, being able to go back and open up my midterm project and just look at it, it's satisfying that there's a tangible thing that I created.

This student feels strongly that projects allow for a more thorough demonstration of understanding because it involved creating a bespoke question, which he felt required a higher level of thinking that the formulaic memorization involved in studying for a test. For him, what is most important is to understand the interconnection of concepts.

> I would even argue that it's a better assessment in terms of understanding, because like, what's the point of having the knowledge if you can't explain it in an accessible way, you know what I mean? The fact that we had to explain our process, I thought was really important. I think in science, a lot of people are not great writers and can't communicate well and so this helps with that because it forced us to develop all the other skills that come with it—the organization and time management and research skills and referencing and the collaboration, just all of that comes with a project and not with a test.

When asked about any disadvantages of a project, he pointed out that a test forces you to think independently. That said, he feels that being able to use the vast resources we have available to us in our daily lives is a more valuable and practical skill. Table 14 displays direct excerpts from this interview.

Table 13

Group Project Student 1 Interview Excerpts

Group Project Student 1 Interview Excerpts	
Theme	**Interview Excerpt**
Chose project topic related to program	"I'm trying to do neuroscience next year for my program and my partner is transferring into physiology and so both of us are very interested in the physics of the body or the physics of how things work in the brain. And so I was like, 'Hey, why don't we do something about that so we aren't bored.' Because we had friends that were doing stuff that they had no interest in and they were so sad, and we were like, 'We don't want to be sad.' So we basically were just smart about picking something that actually seemed interesting to us. And that helped us really engage with the course content because, at the end of the day, when it's something that's applicable to a topic that you care about, it makes it more interesting."
Project is about demonstration of conceptual understanding more than finding finite solution	"I think that at the end of the day, for me, I at least kind of have the understanding that the project's about showing that we understand what's going on, it's not necessarily about coming up with the most complicated or the most kind of complex idea and then apply it, it's more so about, just applying it and then making it make sense to like somebody who else is looking at it."
Project placed more importance on process than 'correct' result	"[W]e had collected a lot of great like scientific data, like numbers for what we were trying to do. And then we were calculating values to verify those numbers and then the numbers were way off, like, several 1000s off. And so we were like, 'this is bad', because it means that we can't back up our calculated value with a scientific data thing. And so that was the point that was made to us in the dropping session was that it's okay if that doesn't quite work out. It's not necessarily about finding a calculated value that is exactly correct. But it's about doing the math and seeing how things might work together to come to an answer, even if it may not be the right answer. And so that kind of thinking was how we tried to not get stressed."
Hesitant of investment required for project	"[T]he reason I was hesitant to do the project before the midterm was that the hours put into a project like this, for me, at least, are going to be probably more hours than I would put in studying for an exam."
Project benefited grades and understanding of concepts	"[It] ended up working out for me because I definitely would have done much worse on the exam than I did on the project. So, from a grades perspective, it was a good call. But I also think that I definitely had to do more work to understand the content for the project, which was good, probably for my overall understanding of physics."
High grade in project meant less stress going into final exam	"[J]ust purely from a grades perspective my stress dropped significantly once we got the midterm project back because I was looking at needing, like a 70 on the exam to when I got the project back, I needed a 45 for an A. Personally, I track my grades, I make sure that I'm on track to do what I want to do."
Did poorly on final exam—better concept retention of project concepts	"[U]p front, I did really well on the project. It saved me for the final exam where I did not need to do very well to get the marks that I wanted in the course. […] I did not do well on the final. The questions that I got correct, I believe, were mostly questions from the first half of the class."
Project allowed for slower, more deliberate learning	"[T]he ability to pace yourself and do it on your own time. I look at something, I sleep on it, I think about a little bit and then I go back to it. Especially with physics, that's how I am able to problem solve. And so having the ability to not be in an exam situation where I have two hours to answer all the questions and like, 'I need to know, and if I don't, I don't have the ability to take a couple of days, even like a week and really think about, okay, now that I know what I'm going to try to do for this project, what can I do? What are the resources available to me and just working through making a good plan, like that ability.' Even just that is huge as an advantage personally, as a learner. That's how I learn."
Benefit of group work—understanding another person's way into a problem	"[My partner] and I think very differently and have a different approach to things. And so the ability to bounce ideas off of each other, do the math together, and make sure we're not making silly math mistakes. All of that also really helped me when, let's say, I'm going to do a final exam—'Okay, I remember, I got this wrong when we were working through it. This is why it was wrong. Cool, I won't do that, again.'"
Project allowed for research into something student was interested in	"I have the ability to go out and do research on, we were working with a motor neuron on a squid, that was cool. I was like, this is really interesting, I wouldn't have learned this had this not existed, had this project not been a thing, I wouldn't have any idea about any of this. And so I definitely like this. [T]he nature of it was probably the most appealing aspect of it out of the other reasons to do it. For me, that was definitely the part that made it worth my while."
Flexible grading scheme allowed lower stress in course because more avenues to gain points for effort	"[P]hysics is scary and first semester physics for everyone is hard and bad. There are very few people I know that really liked that. And so 102 is kind of a nice reprieve from that, because it's still hard and there's still weird stuff going on—it's still physics. It's still necessarily not everybody's favorite, but it's instructed in a way and the grades are set up in a way that that's okay. And so, in my opinion, it is the best structured first year class because it gives you the flexibility to not be good at something and still do well on the class overall because you're putting in the effort."

Table 14

Group Project Student 2 Interview Excerpts

Group Project Student 2 Interview Excerpts	
Theme	**Interview Excerpt**
Project allowed for exploratory learning—discovery of interconnection and application of electromagnetism to biology	"[M]y partner and I wanted to connect it to some kind of biological concept because we're both more interested in the life sciences. And it would also pique our interest in physics more because we tend to just not really appreciate physics, so seeing how it's connected would make us appreciate it more. So we research that area and then, once we saw that the neuron is very similar to a circuit, there are so many connections we can make. And it just helped [us] understand how circuits work better because we can compare it to how a nerve works. And if we understand that, then we can kind of understand how the circuit works. And then we kind of discovered how the myelin sheath is like an insulator. And then we looked at insulators and conductors. And then I vividly remember we were trying to figure out a way to make the question more complex. And so I was just looking at the circuit that we had drawn up the nerve. And then we were trying to come up with like a solution or like a new like drug for MS. And so I thought of like, what if we just add a little junction here and rewire the current? Would that slow down the river that increases the current. I don't exactly remember but it just was a thought that could make it make sense. And then we did the math, and it made sense. And that was just so rewarding because it was just like a direct application. It came from my mind and from the content of the course. And then to see it actually work out with the numbers too was really amazing."
Open-ended nature of project was daunting because unconstrained	"[B]ecause it was so open ended it was really easy to find ourselves in very difficult equations and concepts that we didn't know how to simplify or work with. And it was the hardest part of the project for us was walking the line between making it not so straightforward and making, you know, connecting concepts, deriving equations, but also not going too far to the point where we have no idea what we're talking about and we're, what's the expression, biting off more than we can chew."
Project was stressful because unfamiliar with researching and self-directed learning	"I actually was really stressed about the project, because it was very open ended and it seemed like a very daunting task. But I think that's just because we're not used to that, like all of the tests and projects we're just told what to learn and how to learn it. And we're not really given a chance to think about what we want to study and how we want to go about it. So I really liked that challenge. And once I started, it was not as hard as I thought it would be. Researching one area led to another and we were able to kind of figure it out from there."
Project grade felt more rewarding because of effort and insight from learning process	"[S]eeing my grade for the midterm was so much more rewarding than any other grade I've gotten even grades that were higher than that because it was just a validation of the skills that I thought I had. Whereas tests, if I do well, I kind of feel like I got lucky in the questions I studied or the way I studied having worked out. But this project was a direct result of a lot of thought and time and the way I wrote everything out and the way we went about structuring it and the research. It just felt more personal. […] Even now, being able to go back and open up my midterm project and just look at it, it's satisfying that there's a tangible thing that I created. It feels really nice. And just drawing the diagrams was really fun. And I got to explore the more creative side of me and the artistic side."
Project allowed for deeper understanding as well as other skills to be developed	"I would even argue that it's a better assessment in terms of understanding, because what's the point of having the knowledge if you can't explain it in an accessible way, you know what I mean? The fact that we had to explain our process, I thought was really important. I think in science, a lot of people are not great writers and can't communicate well and so this helps with that because it forced us to develop all the other skills that come with it—the organization and time management and research skills and referencing and the collaboration, just all of that comes with a project and not with a test."
Value in improving research abilities—value in relying on external sources for understanding	"I don't think there's anything wrong with going to Google and getting help that way, or looking at a YouTube video to explain a content concept. I don't think you're ever going to be fully alone in the world and need to know how to do something. There's always people there who know different things than you. So I would argue for having that circle of collaboration, even if not all of it's coming directly from your own mind. You're choosing what to take from different pieces and you're finding where to get them. And I think that's valuable."

Midterm Group Project Student 3

This interview shows a student who is strategic in how much effort and time she wants to invest in this course but also knows that she learns best when she is given free rein to explore a topic that she's curious about (Table 15). She recognizes that she needs to be accountable to others in order to learn. The flexibility of the course structure allowed her to put in a level of investment that she found both satisfying in terms of what she was able to learn and, importantly, not too overwhelming. We see a student on a pre-med track who feels that the *personalized learning* grading scheme provided her with a sense of freedom in how she wanted to approach the course content.

> I think the flexibility of the course made it feel like I was able to dictate how I want to learn. […] Even though it was a really large class, I felt like I had like the political freedom almost to pick and choose how I wanted to navigate the course.

She is motivated by pursuing her own interests, which don't necessarily align with her academic program. Even though she was enrolled in biology, she wasn't interested in applying electromagnetic content to a biology-related context. Instead, she was more interested in learning how a hairdryer worked because it was more relevant to her everyday life. She found a high level of satisfaction from investing in a topic that was of interest to her.

> I've always been interested in physics, I've just never been good at physics. So I think doing this project piqued my interest a little, because it was really nice to see that something that I had put my effort into and something that I had studied for and understood was paying off on the other end because I got a good mark on the midterm project.

This was not this student's first exposure to project-based work. In fact, she shared that she had been in a gifted student's program for five years prior to starting university in which the students were regularly given open-ended assignments which made her more accustomed to and aware of the benefits of demonstrating her understanding through projects. However, the version of open-ended inquiry that was made possible through the midterm project prompted her to think further about the balance between too many constraints and too much freedom to err in the context of this assessment.

> If the learner just so happens to take the criterion in a completely different way than [what] is intended, then you can't give them the mark, right. But you also can't put too

> many guidelines on it, or else it just becomes almost like a test format. So I think that's the hardest line to walk. And kind of biggest things with independent research projects, and independent learning and like the autonomous learning model in general definitely takes a specific learner mindset to approach things. I think a lot of people just don't like doing projects, because they like the rigidity of like being able to just complete an exam.

Because of this, she felt that she received enough guidance from the rubric and the advice that she received from the drop-in sessions to be confident in her final submission. She navigated the course components in a strategic way, accumulating grades from different components to lower the weight of her final exam. This ended up working in her favor because, when it came to the end of the semester, she lost momentum to study for the final exam, which took place on the last day of the final exam calendar. Because she had accumulated sufficient points during the semester, she felt that she didn’t need to worry as much for the final. In fact, she approached the second half of the semester’s content from a very different perspective that she had in the first half. Whereas working on the project had involved in-depth understanding of the interrelation of concepts, her approach to studying for the final exam was more geared toward superficial pattern recognition. Furthermore, although she had developed the ability to explore and apply a concept through the project, she realized that the depth of her conceptual understanding did not translate to being able to perform well on the final exam. Each assessment style required a distinct way of engaging with the course content:

> On the second half of the content, I approached it more with a test studying mindset, which I think why I did better on that part, because I focused more on like, here's some test questions. Here's exactly how to go through these questions. Because when I study for a test, [I] obviously kind of remember the patterns of the question, right, rather than the concept of the question. […] So on the exam, when I saw that question I was like, I've done this, I've seen this, I know how to do this, these are the steps to get there. Whereas when it was a question on the first [half of the] semester, it was like, I can explain to you how this works in real life, and I can explain to you why this is happening but, if you want to plug in the numbers here, that's where I'm kind of kind of falling off the boat a little.

This student admits that her engagement with the course was irregular throughout the semester. She credits the tutorials which helped her to stay on top of her learning. She compares the value

of the tutorials to both the weekly quizzes (CAPA) and the pre-lecture readings, which felt more like "going through the motions [and not] digesting what was happening." In contrast, she felt a greater sense of accountability by taking part in the tutorial environment.
Table 15 displays direct excerpts from this interview.

Midterm Group Project Student 4

This interview shows a student whose experience with the structure of this course had a significant impact on her engagement with and interest in the course material. The opportunity to explore electromagnetism through electroconvulsive therapy left her confident in her understanding and eager to engage in more research down the line (Table 16). We see a student who emerged from this course with a renewed interest in pursuing her own curiosity.

> [T]he project was very eye opening, in terms of material but also self reflection. I've never been one to be excited about physics. And that was a big deal for me. So I guess it just sparked an interest in wanting to be curious more and just seeing how far it can go.

She credits her experience with the project with the feeling of being proud of her work. The impact of the project was particularly meaningful to her because, going into the course, she felt that physics was not one of her stronger subjects. Her favorite part of the project was being able to tailor it to her own interests through finding creative applications to the course concepts. She and her partner ended up choosing to focus on electroconvulsive therapy.

> I think that's one of the reasons it made such a big difference is because it was applicable—I made it applicable to something that I'm really interested in. And so not only was [it] easier to pay attention, but it stuck with me more. […] And I can visualize what I'm learning more.

Initially, she found it challenging to collaborate on an open-ended project with a partner. However, she found value in seeing the content from someone else' perspective.

> We worked on the questions together, but we ended up alternating questions. So, when she was explaining how she did one question and how she formulated it and came up with the solution, there were a few examples where I wouldn't have done it that way. But it still worked. And it was pretty eye opening like that. And even just talking to her when we were brainstorming the questions, if I had done the project by myself, it would have looked completely different than how we did it.

Through this experience, she gained a lot of insight into the other student's approaches to learning. One of the core issues that she highlighted from her experience with the midterm project was the challenge of grasping what you don't understand in such an open-ended learning context. However, her research led her to find new threads to investigate that were very inspiring. She credits the experience of the midterm project which helped her to better understand the concepts from the first half of the course but acknowledges that her understanding of the content from the first half of the course was significantly stronger than the second half, during which the course focused on magnetism and optics.

> It kind of felt like in doing the project, it really strengthened my foundation for those topics. And then for the second half of the material, although I was understanding it as it was coming and I felt competent in it, it kind of felt more surface level. And over the past month of just being home, I know I've forgotten stuff, it just feels like it's not as sticky.

Moreover, because she had received a high grade in the midterm project, she was less stressed going into the final exam but also less prepared. Ultimately, this student sees value to providing students with a grading scheme that they can adapt to their own areas of interest because there's no one-size-fits all approach to learning. Table 16 displays direct excerpts from this interview.

These four interviews portray different aspects of the learning benefits of exploratory and collaborative learning. By struggling through the open-ended nature of the assignment, researching content that they were interested in and working with a partner to solve a complex problem together, these students were able to feed their curiosity in subject matter that they had not been interested in at the start of the semester. However, even more than increased interest in the course material, these students report that the choice of navigating the assessment scheme in their preferred way had an impact on how they understood themselves as learners.

Summary of Interview Findings

These interviews provide significant new insight as we question the implications of introducing learner centered instruction and assessment through a *personalized learning* assessment scheme that included a group-project alternative to a standard multiple-choice midterm test in a large-scale, prerequisite freshman physics course for Life Sciences students. In my opinion, the most interesting aspect of these interview findings is that they show how self-aware and intentional each of these students was in relation to their experience in the course. The survey findings, though still significant, were insufficient in order to be able to distinguish why it was that students navigated the course in the way that they did. By interviewing four students from each assessment stream, we can also pay closer attention to the differences and similarities in experience between students who chose to be assessed in the same way.

As a result of these interview findings, I was able to make the following claims about how students perceived the personalized learning assessment scheme.

- The flexible grading scheme supported students' sense of learner agency.
- The tutorial environments carved out dedicated space for constructive failure in the learning process.
- The concept-bridging midterm group project made space for open-ended inquiry in the learning process.
- Through the midterm group project, in which students had to set their own research parameters, students gained experience with working through uncertainty and indeterminacy.
- Although students reported struggling through the open-ended nature of the project, they also reported that it was this same feature that made it a more valuable learning experience and more memorable to them in the end.
- The project-based midterm rewarded slow, deliberate thought and encouraged students to pace their own learning.
- Exposure to a project-based assessment curated the process of exploratory learning.
- The sense of accomplishment that some students gained from building their own concept-bridging questions that were tied to real-world applications of the course content helped to redefine their notion of educational success by placing emphasis on the quality of their learning experience rather than the grade their project was awarded.

And yet, despite these meaningful results, both the survey and the interviews provide evidence of notable grade-oriented student conditioning amongst this student demographic. We see that, as strategic actors, students will tend to stick to the path of least resistance—the *known* path. Students are able to identify that a project-based assessment would benefit their learning but they will still opt for a test option, if given the choice. This finding suggests that we need to understand these students as strategically-minded grade-optimizers within a highly constrained system. Let us now examine this evidence through an investigation into the course' grade-based trends.

Table 15

Group Project Student 3 Interview Excerpts

Group Project Student 3 Interview Excerpts	
Theme	**Interview Excerpt**
Flexible grading scheme provided learner agency	"I think the flexibility of the course made it feel like I was able to dictate how I want to learn. […] Even though it was a really large class, I felt like I had like the political freedom almost to pick and choose how I wanted to navigate the course."
Enjoyed applying concepts to daily life through project	"Even though I did something redundant like a hairdryer, it was really cool to see how even that could be applied to thinking in the long run. I was like, 'if this can be applied here, how else can it be applied to other places', which is what piqued my interest specifically."
Project piqued interest in physics	"I've always been interested in physics, I've just never been good at physics. So I think doing this project piqued my interest a little, because it was really nice to see that something that I had put my effort into and something that I had studied for and understood was paying off on the other end because I got a good mark on the midterm project."
Open-ended and self-directed nature of project makes it beneficial to learning	"If the learner just so happens to take the criterion in a completely different way than [what] is intended, then you can't give them the mark, right. But you also can't put too many guidelines on it, or else it just becomes almost like a test format. So I think that's the hardest line to walk. And kind of biggest things with independent research projects, and independent learning and like the autonomous learning model in general definitely takes a specific learner mindset to approach things. I think a lot of people just don't like doing projects, because they like the rigidity of like being able to just complete an exam."
Fewer project guidelines allowed for more creative concept application	"In my personal opinion, if you had added more guidelines, it would have made it a little stricter and made it harder for people to come up with the ideas that they did."
Less engaged going into final exam	"I was like this is the end, I really don't care anymore. I think because I had known I'd set myself up nicely in the beginning, I was like, yeah, this is kind of a hit or miss."
Difference in learning approach between project and exam	"On the second half of the content, I approached it more with a test studying mindset, which I think why I did better on that part, because I focused more on like, here's some test questions. Here's exactly how to go through these questions. Because when I study for a test, [I] obviously kind of remember the patterns of the question, right, rather than the concept of the question. […] So on the exam, when I saw that question I was like, I've done this, I've seen this, I know how to do this, these are the steps to get there. Whereas when it was a question on the first [half of the] semester, it was like, I can explain to you how this works in real life, and I can explain to you why this is happening but, if you want to plug in the numbers here, that's where I'm kind of falling off the boat a little."
Tutorials were most beneficial to learning	"For me, in tutorials, being forced to sit down, and turn on my camera and being forced to answer these questions, it's kind of nerve wracking, but at least for me, it was actually where I learned and obtained the most content."
Tutorials provide social accountability	"I enjoy being thrown in a room of people who don't know who I am. In the moment I obviously hated it, but that also motivated me to not look like a dumbass, which kind of forced me to do the problem."

Table 16

Group Project Student 4 Interview Excerpts

Group Project Student 4 Interview Excerpts	
Theme	**Interview Excerpt**
Project sparked broader curiosity	"[The project was very eye opening, in terms of material but also self reflection. I've never been one to be excited about physics. And that was a big deal for me. So I guess it just sparked an interest in wanting to be curious more and just seeing how far it can go."
Project sparked deeper curiosity in physics	"[This] was a first for me, especially in physics. I felt like I turned over this big leaf. It was a really big deal."
Self-directed concept application increased content retention	"I think that's one of the reasons it made such a big difference is because it was applicable—I made it applicable to something that I'm really interested in. And so not only was [it] easier to pay attention, but it stuck with me more. […] And I can visualize what I'm learning more."
Collaborative work was beneficial but challenging	"Working with a partner, it was difficult because we both kind of had different interpretations of the rubric, or lack thereof. And I thought it would be a fun challenge. And just convincing my partner of working together in that way was a bit tricky."
Collaborative work provided insight into another person's approach to content—enhanced project quality	"We worked on the questions together but we ended up alternating questions. So when she was explaining how she did one question and how she formulated it and came up with the solution, there were a few examples where I wouldn't have done it that way. But it still worked. And it was pretty eye opening like that. And even just talking to her when we were brainstorming the questions, if I had done the project by myself, it would have looked completely different than how we did it."
Collaborative work highlighted different approaches to learning	"I would say especially working with someone else on the same thing really just highlighted how we learned differently. I would notice [that] she was going back to the slides and class to look at practice problems that we had done to get some inspiration from there. Whereas I had completely forgotten about anything we had worked on as a class. And I was trying to research stuff—I was trying to create it from scratch. So that was interesting."
Fewer project guidelines meant less clear expectations	"[S]omething that we ran into is, because no one else is doing, no one else is working alongside us, it was difficult at times to figure out what we were missing. Like, we knew there was an issue, but we didn't know what and trying to articulate that."
Project experience strengthened deeper conceptual understanding	"It kind of felt, in doing the project, like it really strengthened my foundation for those topics. And then for the second half of the material, although I was understanding it as it was coming and I felt competent in it, it kind of felt more surface level. And over the past month of just being home, I know I've forgotten stuff, it just feels like it's not as sticky."
Felt more confident in concepts applied in project during final exam	"[I]t can go both ways. I definitely could have studied more, so it kind of gave me too much confidence, in a way. But I wasn't naive. I've still studied a lot and stressed about it but I felt more confident in the first half of the material, which made it easier to study. Like the rest of it instead of the whole course."
Challenge of providing assessment styles for different kinds of learners	"I think it comes down to what kind of learner you are, so it could vary from person to person. I know there are people who are very good at memorizing and then application is not, they're not very strong in that, so of course they will tend to do better on a multiple choice test. So I guess the disadvantage is that you can't really make it perfect for everyone. You can't please everyone but giving the option was a pretty good way to do that."

Evidence of Grade-Based Student Conditioning

Table 17 shows the grades of the entire class after both midterm assessments. At this point in the semester, we see that, although the midterm test scores are on par with general averages for this course, there is a significantly high mean and median grade for students who took part in the midterm group project. As such, many of these students went into the final exam having accumulated sufficient points to pass the course even if they received a very low result on the final exam.

Table 18 shows the mean and median grades of students in the final exam. What we see is that, even though the median grade of the midterm test students in the final exam remains close to that of their midterm results, there is a dip in over 40% between both assessments for group project students. There are a variety of factors that could go into explaining this downward plunge, however, as was explicitly stated in the interviews, some students who had accumulated high grades in the course through the flexible grading scheme that offered students many avenues to collect participation points, went into the final knowing that they only needed approximately 45% in order to get an A in the course.

Table 17

Midterm Assessment Grades of Both Student Cohorts

Midterm Assessment Grades		
	Midterm Test Student Grades	Midterm Group Project Student Grades
Mean	73.3%	87.5%
Median	73.3%	95%

Table 18

Final Exam Grades of Both Student Cohorts

Final Exam Grades		
	Midterm Test Student Grades	Midterm Group Project Student Grades
Mean	65.1%	51.5%
Median	70.2%	52.6%

Table 19 shows that this strategic approach did, in fact, pan out. Even though many of the group project students did poorly on the final exam, their cohort's final grade in the course was almost exactly the same as that of the midterm test students, despite doing significantly worse on the final exam. At the end of the semester, both groups averaged out at approximately 80%, or the equivalent of an A in this course.

Table 19

Cumulative End of Semester Grades of Both Student Cohorts

Cumulative End of Semester Grades		
	Midterm Test Student Grades	Midterm Group Project Student Grades
Mean	79.2%	80.5%
Median	82.1%	81.5%

This evidence of strategic grade-optimization is further underlined when we examine the grades of the interview students (all of whom agreed to share their grades for the purpose of this study). The following table shows a significant decrease in many of the final exam grades of all of the midterm group project students. While, in contrast, three out of the four midterm test students remained almost perfectly consistent between their midterm and final exam results.

Table 20

Interview Student Course Grades

Name	Midterm Choice	Midterm Grade	Final Exam Grade	Cumulative Final Course Grade
Student 1	Midterm test	100%	96.5%	98.5%
Student 2	Midterm test	66.7%	36.4%	66.7%
Student 3	Midterm test	100%	100%	93.4%
Student 4	Midterm test	100%	96.5%	97.7%
Student 5	Midterm project	95%	62.3%	88.7%
Student 6	Midterm project	90%	59.7%	82%
Student 7	Midterm project	100%	40.4%	84.4%
Student 8	Midterm project	85%	34.2%	68.6%

In conclusion, through these findings, we see that providing students with the opportunity to creatively apply course content to an area of their own interest has the potential to stimulate a learner's desire to probe deeper into their understanding of the course material and, possibly, to retain more of it in the process. Moreover, this research demonstrates that, even at scale, it is logistically feasible and pedagogically worthwhile to implement alternative methods of instruction and assessment to freshman-level students. And yet, because of the prescribed nature of these courses, they are often perceived by students as little more than a necessary hurdle to cross in order to gain access to upper level content that is more aligned with their specialized areas of interest. Despite attempts to introduce more student-centered learning into the course structure, our findings show marked resistance amongst members of this student demographic (over 50%) to engage with a high-stakes project-based assessment approach due to self-reported grade optimization concerns and general reticence to choose a grading scheme that presented them with greater uncertainty. In the next chapter, we will discuss how a shifting in my interpretive lens of the research findings led to a broader questioning of the incentive structure of the education system. This reframing leads me to make the case for process-oriented learning in introductory physics, despite institutional obstacles, and to highlight the implications of this perspective on assessment in the age of generative artificial intelligence.

> [T]he investigation of thematics involves the investigation of the people's thinking—thinking which occurs only in and among people together seeking out reality. I cannot think for others or without others, not can others think for me. Even if the people's thinking is superstitious or naïve, it is only as they rethink their assumptions in action that they can change. Producing and acting upon their own ideas—not consuming those of others—must constitute that process. (Freire, 1970, p. 108)

Chapter 5: Discussion

My Epistemological Framework: A Shift in the Lens of Interpretation

Building upon the conceptual and methodological frameworks outlined in the second and third chapters, if our intent is to reevaluate the modes of assessment that govern our systems of education, then to use the same, staid mechanisms of measurement to evaluate the learning process is to fall into solipsism. To evaluate assessment—to evaluate the formalized system through which the demonstration of knowledge is assigned value—is to question the methodological framework that is so deeply embedded in the norms and practices that uphold the structure of formal education that we fail to differentiate them from the system, itself. To question the operating premise of a system is to inject chaos into its foundation. It is to invite scrutiny. Ultimately, to question is to probe the integrity of a system—and what results from that perturbation exposes its internal logic. To question, therefore, with both its destructive and constructive forces, is to care for the system's health. With this framing in mind, my inquiry into the ways in which learning is assessed comes from a desire to reconsider where we place value in the formalized process of learning, with the ultimate ambition of revitalizing the system as a whole.

"Matters of meaning are shaped—that is, enhanced and constrained—by the tools we use." (Barone & Eisner, 2012, p. 2) In order to exist within the structure of everyday life, it can be so easy to take these measurement tools for granted. They slip into the background of our mundane day to day and, the more we are blind to them, the easier it becomes for our motivations and actions—where and how we bestow value—to be dictated by these externally imposed mechanisms. (Denzin & Lincoln, 2018; Smith, 1987) But these methods of meaning-making are far more diverse and malleable than we tend to realize. The purpose of the social sciences is to uncover the processes that govern the individual's social consciousness, whereby the act of framing and reframing the individual's perspective on themself and the community around them serves as a method to disentangle the superimposed layers of meaning that ensnare us all, simply as a result of existing within a social reality.

When this research began, five years ago, my perspective on the malleability of the epistemological framework that I had at my disposal was far more passive than the active stance I have, since, chosen to take. This paradigmatic expansion is, in my opinion, indicative of the intellectual growth that has characterized my time in academia. It embodies the endless process of building, casting off, renegotiating, and refining the terms and constraints of the framework through which you are making sense of the world. It is *the* epistemological project—understanding the nature of knowledge—in all its subjective and relational complexity. In my own case, the crux of this exercise has been a reconciliation between a social science mode of synthesizing understanding and a physical science mode of knowledge production. This reconciliation has necessitated the construction of a bespoke interdisciplinary lens through which to measure information and extrapolate meaning.

Within the field of Physics Education Research (PER), standard methodological practices often reflect the epistemological frameworks of those conducting this kind of research—physicists. To be a physicist is to deal in reduction and abstraction. Physics, like every other discipline, operates according to many hidden assumptions as a methodological means to derive order from disorder. It is a field driven by quantitative reasoning—mapping the world through the use of mathematical models. (Meredith & Redish, 2013, p. 39) And, for this reason, physicists who engage in educational research tend to employ quantitative reasoning in pursuit of what is, effectively, a social science. In an effort to abide by convention, my initial approach to studying this pedagogical problem was to focus on the *what* and the *how* of what I was observing. What pedagogical tools can impact the depth of student learning? How have these innovative measures shifted student grades and attitudes? And how can the past semester's results inform new, and improved pedagogical interventions?

This focus on the *what* and the *how* were, by no means, a mistake. However, they were not the right questions to be asking to address what I was really curious about—the *why*. The culmination of this research has, thus, deviated from its original trajectory. It has become an attempt to understand the deep-seated behavioral norms that govern the ways in which students choose to navigate the structures of formal education. This research is built upon the premise that, within the formal education system, students are to be understood as intelligent and strategic actors. And, therefore, observable trends in behavior are not arbitrary and cannot be addressed with superficial-level remedial practices. Instead, these trends are to be taken seriously as manifestations of the underlying tensions that result from the system's rules of engagement. As such, my framing of the topic in question had to be stretched in both depth and scope. In terms of depth, it had to take into account individual students' perspectives of navigating their educational experiences. In scope, it had to take on what some researchers have termed critical bifocality—inquiry informed by the conversation between the personal and the systemic levels of analysis. (Denzin & Lincoln, 2018)

In the context of this research, my role can perhaps best be described as that of a physics education ethnographer—studying the internal culture of a learning community by interpreting emergent behavioral patterns and tying these findings back to the ways in which perceptions of learning inform approaches to learning. From this perspective, the methodological framework that this research has morphed into is perhaps more aligned with that of an institutional ethnography, in its commitment to "investigate social life in terms of how it is actually organized" (Smith, 1990, p. 631) by highlighting "the discrepancies between the way a regime of power seeks to appear to maintain legitimacy and how it is experienced in people's lives." (Nichols et al., 2017, p. 108) These discrepancies or points of tension in a given system tell the story of how individual experiences are shaped by broader institutional and political-economic relations. Through this co-investigation, the researcher and participants come to perceive that what they've internalized, historically, as personal failings or struggles can be understood as systemic, structural, institutional issues. The emergent sociological patterns can then be used to map out a more telling account of an institution's internal structure than could ever be understood from an external source. As Smith puts it,"[t]he more we can collectively understand and map the social relations organizing us, the less they will just be forces standing against [us] and overpowering [our] lives." (Smith, 1987, p. 133)

At its most abstracted level, this research has been an exercise in maintaining a posture of inquiry throughout the construction of my own bespoke interpretive framework. It is, if nothing else, an attempt to build "a research method that is at the edge of inquiry." (Barone & Eisner, 2012, p. 4) And, as such, this matrix of interpretation needed to be, at once, stable enough to maintain structure and flexible enough to withstand the endless reorganization of its internal logic. With this as a primary goal, this research operates as a form of heuristic case study whereby the researcher's developing understanding of a given phenomenon serves as a means to refine and strengthen the very instrument of analysis. (Mitchell, 2006; Marquéz, 2019, p. 399) This approach invites audiences to question hegemonic norms as a means to "disturb conventional understanding." (Cahnmann-Taylor, 2018, pp. 249-250) From this posture of inquiry, the aim of this research is little more than to discover what epistemological multiplicity can tell us about using the tools of the social sciences to better understand physics education.

With this aim, the primary conclusion that I have drawn from this investigation into the internal machinations of the higher education system is that the type of learner we are cultivating is determined by the way in which we score the learning process.

> "The instrumental and moulding models of education provide a caricature of this necessary feature of desirability by conceiving of what is worth-while as an end brought about by the process or as a pattern imposed on the child's mind." (Peters, 1965, p. 62)

Towards an Evaluation of Assessment

How do we judge a student's worth? Though the answer to this question may remain perennially rhetorical, the reality of its implications for a learner within the formal education system run deep. The rules of a game undeniably impact how a player will move within it. The same is also true within the context of higher education, where the constraints of a highly standardized educational system overwhelmingly privilege a strategic navigation mode that reinforces quantifiable grade-based achievement over the more qualitative and non-linear process of constructing knowledge through the cultivation of curiosity. (Kohn, 1999; Scouller, 1998; Shankar & Zurn, 2020) Constraints matter. They serve to guide the direction of one's progression. Structure matters. Disciplinary knowledge requires a learner to be trained in accordance with a highly codified system. And yet, understanding how to follow rules is not sufficient to produce creative thinkers who can transcend them. (Davis, 1976; Tampio, 2019) Curiosity matters too and it is the secret ingredient that unleashes the creative mind. (Davidson & Katopodis, 2022; Shankar, 2020) Curiosity, however, is fickle and needs constant nurturing in order not to be stamped out once formal evaluation is introduced into the learning equation. Can the formal higher education system cater to a learner's curiosity while retaining the constraints necessary to demonstrate disciplinary mastery? And, if so, which learners are granted agency in their formal education experience—where do novices fit into this question of learner agency? (Shankar & Zurn, 2020; Bandura, 2006)

Scholarly research in science education today tends to focus on transmissionist approaches to quantifying the outcomes of teaching and learning. This tokenization of the learning process allocates a disproportionate amount of weight to the study of the *what* that is being learned rather than the *how* and the *why* this information is being integrated by the learner such that it can be applied to various contexts. (Tanner, 2013, p. 322) But what if the framing shifted? What would it look like to privilege modes of instruction and assessment that reinforce a learner's engagement with different modes of knowledge integration? Despite significant innovation in teaching methodologies in university-level science education, grades remain the single most important marker of a student's demonstration of understanding; a sanctioned proxy for knowledge acquired. Grading is not inherently to blame but what is being graded needs to be considered at a more granular level in order to better chart a learner's progression. (Dixon-Roman, 2017; Schinske & Tanner, 2014) Within the context of higher education, a shift towards active learning teaching strategies must be driven home by assessment schemes that encourage process-oriented over outcome-oriented learning. (Swinton, 2010) Moving towards process-oriented assessment requires grading rubrics that incentivize learner curiosity while disincentivizing a mere recall to points. (Butler, 1988; Kohn, 1999; Schinske & Tanner, 2014; Swinton, 2010) This pedagogical shift calls for an overhaul of the traditional assessment styles characteristic of most undergraduate science courses. (Davidson & Katopodis, 2022; Holmes & Bonn, 2015; Stranger-Hall, 2012; Kitchen et al., 2006)

Before addressing the implications of an assessment approach that reinforces the process versus the product of learning, we must first consider the student demographic in question. Within PER (Physics Education Research) there is special consideration reserved for the teaching of freshman physics to Life Science majors, for whom introductory, large-scale prerequisite courses represent their last mandated exposure to the principles and methods of physics during their undergraduate degree. Though the majority of these students will not go on to pursue careers in this field, a solid grounding in the laws of physics is necessary to enhance their understanding of the natural sciences. (Physics Survey Overview Committee, 2001) Despite this, because of the prescribed nature of these courses, they are often perceived by students as little more than a necessary hurdle that must be crossed in order to gain access to upper level content that is more aligned with their specialized areas of interest. This begs the question, can the structural components of course assessment influence the manner in which strategically-minded students navigate a prerequisite course in order to enhance their curiosity in subject matter they did not seek out?

> Insofar as schooling continues to be thought of as a mechanism, it ceases to be an invitation to the world: to construct meaning, understand how it functions, challenge existing orthodoxies and find a way of living with it on one's own terms and as part of a collective. (Hoveid, 2019, viv)

Making the Case for Process-Driven Learning in Introductory Physics

Incentivizing Learner Accountability Through Deliberate Practice

A first implication of reorienting an assessment structure in introductory physics to reward process-driven learning has to do with incentivizing learner accountability. Considering the beginner level of freshman science students, many of whom come in with little to no background in physics, it is reasonable to assume that these students should be held accountable for their progression through the course content. In large-scale classes, often comprised of hundreds of students, the most efficient way to encourage regular, active engagement with the course content is done with the help of frequent low-stakes quizzes meant to test the individual learner's application of the material. Students may seek out support for these quizzes from members of their teaching team but, typically, this mode of assessment is designed to be carried out on one's own. Conditioning deliberate practice into a learner's habits is central to the structure of most institutionalized education. (Bronkhorst, et al., 2014) But could this low-stakes approach be reimagined such that it reinforces a student's ability to navigate a problem rather than their ability to simply show their end result? What ends up being reinforced when a student's ability to show how they reached their conclusion is not accounted for? How can an instructor better understand and redirect their students' misconceptions when the how of a student's process is opacified? More often than not, this type of assessment facilitates an approach to learning that does little to prevent students from rushing through the course content or sharing their ready-made correct answers with their peers because the only thing holding them accountable to their 'measurable' learning is whether or not they have arrived at the correct answer.

Therefore, the question becomes how do you develop learner accountability and regular interaction with the course content for a strategic student within a formalized learning structure without unintentionally overemphasizing a simple recall to points? A more meaningful way to keep students accountable for their learning is through repeated exposure to the material through regular access to a discursive learning structure that offers participation points for active student engagement. This can take the form of a peer group tutorial-type environment in which students are encouraged to work through problems together while receiving the benefit of exposure to different (and differently valid) ways of approaching the same problem. Students accounts reported in this study confirm this—the tutorial environment encouraged students to engage further with their learning. As one student noted, “I think learning in tutorials is probably where most of my understanding came from.”

Thus, social incentives can act as informal yet significant constraints that motivate a learner to develop their own individual understanding while also creating a learning culture that privileges transparency and difference. Rather than disincentivizing a student from sharing their work, this approach sanctions collaboration. In a group setting, where students are granted a pass/fail type mark in recognition of their contributions to the understanding of their peers, reaching the solution to a problem becomes its own reward. Thus, learner accountability and mandated deliberate practice are retained but new bonus benefits to the process of integrating knowledge are unlocked that develop learner resiliency while simultaneously decreasing widely reported student anxiety. (Bowen, 2021) One of the reasons for this is because small group relational learning environments also serve to break down the highly anonymous reality of introductory courses and transform them into socially rich opportunities for students to develop meaningful social ties in their first year of university.

Furthermore, by exposing students to other learner’s methodologies, students’ minds are opened to alternative ways of approaching a problem, thus developing their metacognitive abilities. What’s more, the process of mentoring a fellow student through one’s own trajectory also helps to solidify the understanding of both the mentor and mentee. Critically, this structure allows for learning environments in which students are no longer afraid to make mistakes because it is their effort and engagement that is awarded points. During one of the interviews, a student confided that she felt that seeing others struggle through problems during the tutorials made her feel less alone: “[I]t was also just reassuring and helpful to see that some of the students are having the same sort of difficulties with certain concepts as I was." Creating designated space for constructive failure is fundamental to the process of deep learning. Sadly, many of the standard approaches to formal education stigmatize failure and this stigmatization of failure stifles a student's inherent curiosity, with lasting deleterious consequences. There must be opportunities within higher education where it is okay to be wrong because making mistakes is essential to the process of learning and thinking scientifically. (Tanner, 2013, p. 328) According to this reframing, structure remains just as important as ever but this structure can be used to incentivize learner accountability through deliberate practice by privileging a student's participation in discursive exchange rather than solely focusing on their ability to achieve a correct final answer. This reversal sets off a myriad of beneficial outcomes that increase a learner's metacognitive abilities as well as their confidence in approaching new, challenging problems.

Self-guided Inquiry for Freshman-level Students

A second implication of building assessment structures that reward process over outcome is the place and purpose of cultivating learner agency through inquiry-based learning models. When is a learner ready to take on self-guided inquiry? As newcomers to the discipline, are undergraduate students sufficiently equipped to apply their understanding in creative ways? Physics is known for being a field of research that requires rigorous training and is often touted as one of the most challenging and inaccessible departments on a university campus. The need to train students in order to prepare them according to rigid disciplinary standards is fully legitimate. Historically, the privilege of exploratory learning was most often reserved for graduate-level students who had successfully demonstrated disciplinary mastery according to standard examinations.

Where exploration is concerned, there is always an element of risk. In the context of formal education, unconstrained self-guided inquiry in a student's learning process can increase the chances of misunderstandings in the short-term. And, when the stakes are raised, the premature application of incorrect knowledge acquired by means of exploratory learning, before a student is fully equipped with disciplinary mastery, can lead to a degree of failure that can have lasting consequences on a student's ability to navigate their academic path. Unfortunately, the freedom to meander and make mistakes in the learning process is largely undervalued and often discouraged in formal educational systems. In most institutional structures, students who take less risk often receive the most academic reward for their efforts. (Moran, 2015) A sobering look past the assumptions of the merits of traditional education exposes much of the learning that takes place in universities today as a system in which students are encouraged to engage with subject matter at an often superficial level because the bulk of how they are taught and tested places merit on memorization and pattern recognition rather than deeper conceptual understanding. (Tawfik & Lilly, 2015; Graham, 2019)

By and large, an important consequence to this learned risk averse behavior is that students have become accustomed to taking a passive role in their own learning, expecting to be spoon-fed kernels of information necessary to pass a test rather than to achieve a more well-rounded sense of intellectual autonomy. (Kloss, 1994) Although the onus on deeper learning ultimately lies in the hands of the learner, it must be recognized that this short-sighted approach to education on the part of students is a byproduct of educational structures that reinforce the importance of high grades over holistic learning. (Graham, 2019) Moreover, this trend conditions intellectually gifted and strategically minded students to navigate their courses with a methodology that runs counter to scientific inquiry. It is not uncommon for students who have historically been high achievers at the undergraduate level to encounter difficulty with the exploratory, self-directed nature of many graduate programs. (Moran, 2015) Self-directed, autonomous learning is further discouraged at the undergraduate level. However, the question becomes can and should learner agency be reintroduced at every level of higher education, even for students in introductory courses? This line of inquiry leads me to question the place of qualitative assessment in freshman physics.

The Value of Qualitative Assessment in Freshman Physics

Process-oriented evaluation requires a level of qualitative assessment, which can take many forms but is typically administered as project-based assignments in which students are asked to grapple with course content in a manner that introduces a level of self-guided inquiry into the learning process. This reframing of expectations leads students to have to formulate both the scope and structure of their work in a way that tickles a learner’s curiosity. However, qualitative assessment also introduces a world of new variables into the evaluation process. Unlike the automated correct/incorrect binary of most quantitative evaluation, a marker’s subjectivity now plays a central role in evaluating the level of a student’s demonstrable understanding. Standardized rubrics can only go so far to keep this new level of variability caused by human subjectivity in check. The consequences, therefore, of introducing bias into the assessment process are non-negligible.

The issues of grader subjectivity aside, qualitative assessment also introduces the fear of reinforcing a learner's misconceptions. Freedom to explore also means freedom to go down the wrong path. This raises the issue of building disciplinary intuitions. For a beginner in a given field, for whom these disciplinary intuitions have not yet had a chance to mature, it is significantly easier to be led astray without robust guardrails in place. Therefore, the question becomes are we failing students by providing them with too much freedom too soon? Should climbing the pyramid of Bloom's taxonomy be understood as a strictly linear process? In order to address these questions, it becomes necessary to look into what can be understood as the purpose of formal education. If the goal of education is to support a learner in their acquisition and integration of knowledge, then how we go about defining this term will have an impact on the aspects of a learning environment we, as educators, bring to the forefront. In order to set the groundwork, I turn to the writing of John Dewey, a prominent educational reformer and the father of functional psychology, in his seminal work Democracy and Education:

> [K]nowledge is a perception of those connections of an object which determine its applicability in a given situation. . . Thus, we get at a new event indirectly instead of immediately—by invention, ingenuity, resourcefulness. An ideally perfect knowledge would represent such a network of interconnections that any past experience would offer a point of advantage from which to get at the problem presented in a new experience. (Bassett, 2020, p. 57)

According to this definition, a learned person is one who is able to understand the interconnections of the information stored in their internal arsenal such that they can elicit a creative reinterpretation of this information when applied to novel contexts. Dewey's definition describes the path of learning as one that is, by its very nature, non-linear. As such, the process of training the intuitions that underly the logic of a set discipline can, arguably, be developed through different methodological approaches. To better explain the implications of this perspective conceptually, I turn to the metaphorical description laid out by Paul Hirst in his work entitled Liberal Education and the Nature of Knowledge:

> [U]nderstanding a form of knowledge is far more like coming to know a country than climbing a ladder. Some places in a territory may only be get-at-able by a single specified

> route and some forms of knowledge may have concepts and relations that cannot be understood without first understanding certain others. But that countries are explorable only in one way is in general false, and even in mathematics, the most strictly sequential form of knowledge we have, many ways of coming to know the territory are possible. (Hirst, 1972, p. 91)

If the integration of knowledge can and, perhaps, should be gotten at by vastly different methodological approaches, then why is this not represented in the manner in which we evaluate the learning of students at every level of their education? From this perspective, perhaps, in spite of its inherent complications, it is more pedagogically responsible to provide opportunities for exploratory learning to all undergraduate students. That said, the merit of this statement does not undermine the pedagogical value of flexible scaffolding structures or ‘training wheels’ that are necessary for a student to develop the intuitions needed to progress according to the internal logic of a codified discipline.

Strengthening Learner Agency

I now turn to the underlying and often overlooked importance of agency in the setting of formal education. The cultivation of curiosity motivates a learner’s desire to explore, which, in turn, sets in motion the self-reinforcing processes of concept integration and reformulation inherent to learning. Physicist and educational researcher, Natasha Holmes, underscores the necessity of ‘high agency’ for inventive thinking, which is characterized by a combination of autonomy and limited externally imposed scaffolding. (Holmes, 2013) Central to this depiction of agency is the element of choice. When students are provided with a sense of choice, “volition, self-determination and responsibility” (Nilson, 2016) ensue. In contrast, the absences of these conditions in an overly prescribed and curated learning environment can have the effect of undermining a leaner’s inquisitiveness, thus reinforcing feelings of apathy and passivity in the learner. When the driving ethos becomes: ‘What are you curious about?’ rather than ‘Apply what was told to you in class,' the rules of the game are turned on their head. The novelty of this opportunity to pursue self-directed work was highlighted in one of the interviews:

> I actually was really stressed about the project because it was very open ended and it seemed like a very daunting task. But I think that's just because we're not used to that, like [in] all of the tests and projects we’re just told what to learn and how to learn it. And we're not really given a chance to think about what we want to study and how we want to

> go about it. So I really liked that challenge. And once I started, it was not as hard as I thought it would be. Researching one area led to another and we were able to kind of figure it out from there.

With this in mind, I return to the implications of building exploratory, agential learning into the bedrock of the undergraduate physics curriculum. It is my opinion that the merits of allowing open-ended, curiosity-provoking qualitative assessment schemes into formal education far outweigh the risks that are also entailed. Providing students with the choice to explore in their formal educational experience has the further effect of unlocking a wealth of ulterior positive outcomes. For one, project-based assessment allows students to embed their learning into contexts of their own choosing, which may increase the perceived significance of theoretical work, thereby reinforcing their retention of the subject matter and exposing them to interdisciplinary thinking. (Stigendal & Novy, 2018) Moreover, although most traditional evaluation is administered through one-and-done-type testing which is notorious for heightening anxiety levels in students and runs counter to the merits of iterative learning, projects, which can be carried out over a longer period of the semester, give students more time and space to think through the process of framing and reframing a problem.

Just as there are intuitions for disciplinary research, there are also intuitions to the process of inquiry. Allowing students the opportunity to grapple with their own metacognitive processes when the stakes are still low helps to build a student's confidence in their ability to "think under turbulence," (Mende, 2017) which will undoubtedly serve them beyond the confines of the academy. A less structured approach to creating a learning environment encourages the "reconstruction of experience" (Tenenbaum 1959, p. 298) necessary for deeper-level learning. The pedagogical goal of this type of learning environment is not simply to gain factual knowledge but to understand how to navigate the complexity of uncertainty, which aids the learner to develop psychological resiliency to being thrown into the intellectual deep end. However, perhaps most crucially of all, this pedagogical approach removes the preconception that there are only set things to be learned and that we can know what they are from the get-go, which runs counter to the epistemological framework needed for innovative scientific discovery.

Despite having made a case for the multidimensional value of including relational and exploratory learning into the formal assessment scheme for undergraduate physics students, the question of how to fairly evaluate the depth of a learner's idiosyncratic methodology and creativity persists. This already complex question is exponentially complicated when the logistical constraints of scale, a defining feature of most introductory freshman physics undergraduate courses, are added to the mix. Though there may not be one clear answer to this problem, I believe that a solution lies in the reframing of the place and purpose of assessment in these courses.

The type of learner we are cultivating is determined by the way in which we score the learning process. If, in the words of Lani Watson, an educational philosopher from the University of Edinburgh, we—those constructing a learning environment—choose to hold the trait of inquisitiveness as a "primary intellectual virtue to educate for," (Watson, 155, pp.156-7) then a far-reaching reorganization of the assessment structures of these introductory courses must be forthcoming. The question of how we choose to determine a student's worth continues to echo in my mind. I believe that any attempt to answer this question earnestly will entail a reevaluation of how we assess failure in an academic context. A reassessment of the importance of iterative learning that caters to constructive failure in the formal education system is, in my opinion, the only means by which to breathe life back into an institutional approach that has, systematically, come to run counter to the intrinsic intuitions of life-long learning.

In conclusion, this chapter has opened the door for a broader discussion of the many implications of the findings presented in the previous chapter. Acknowledging a significant shift of the epistemological lens through which I have come to understand this research, has served as a means to investigate the question of how the formal education system values its students—as customers or as learners. The findings are clear, however, that there is a case to be made for the implementation of process-oriented learning at every stage of higher education, including large-scale prerequisite courses where grade-based incentives opacify the learning needs of students self-aware enough to understand the implications of their choices in favor of efficiency. Concern over the value of higher education is taking up more space in today's public forums. As the price of an education increases and its superficially perceivable benefit is put into question, the future of formal education is in greater jeopardy, especially when powerful analytical tools become readily available. In the final chapter, I offer my conclusions to this line of thought, which include my own testament to the transformative power of a graduate degree.

Chapter 6: Conclusions and Implications

Study Conclusions

This research has sought to understand the implications of introducing learner centered instruction and assessment through a *personalized learning* assessment scheme that included a group-project alternative to a standard multiple-choice midterm test in a large-scale, prerequisite freshman physics course for Life Sciences students. The following section represents my interpretation of what my findings show to have been gained and lost through the introduction of a flexible grading scheme that introduced collaborative and exploratory learning into the purview of this student demographic.

What was gained?

- Students gained a sense of agency and motivation by being able to choose their modes of instruction and assessment.
- The *personalized learning* assessment scheme reinforced students' sense of accountability over their work.
- The different components of the course rewarded deliberate practice.
- Access to collaborative learning allowed students insight into the peers' problem-solving process which allowed for more authentic epistemological complexity in how they approached their own learning.
- The collaborative nature of some course components encouraged social accountability in the learning process.
- The tutorials allowed students to feel less vulnerable about making mistakes.
- The concept-bridging group project fostered curiosity in the course content by creating opportunities for inquiry through slow, self-directed learning.
- Having more time and choice to work on the concept-bridging group project encouraged the process of iteration and exploration in a lower-stress learning environment.
- The open-ended nature of the group project created space for discovery.
- The learning emphasis of the group project was on building a route toward an answer more than on getting one correct answer.
- Some students felt that the project allowed them a better opportunity to demonstrate their knowledge.

- The challenge presenting by self-directed, open-ended inquiry was deeply rewarding to some students.
- Applying the course content to an area of their own interest made the course much more stimulating.
- Experience with research in this course made the prospect of undergraduate research more accessible.
- Some students reported better retention of the content from the first half of the course because of what they learned from creating their own concept-bridging questions.

Based on these findings, we see that the *personalized learning* assessment scheme privileged process, exploration, and collaboration. Many students gained a significant sense of ownership over the course content and, even students who opted for the midterm test, recognized that applying course concepts would be more beneficial to their understanding of electricity and magnetism.

What was lost?

- Many freshman students are adapting to the university course load—their main concern is maximizing their time rather than getting the most out of their learning.
- Some students preferred to be tested on their breadth of understanding rather than diving into only select concepts.
- Some students who went into the final exam having accumulated high grades throughout the different course components felt that they did not need to invest as much effort in studying for the final exam and therefore invested less in the second half of the course content.
- Learnings from a collaborative inquiry-based project do not automatically transfer to success in traditional test-based assessment.

Hurdles to inquiry-guided learning for this student demographic

- Familiarity with alternative modes of assessment impacted student interest in or resistance to the alternative assessment option—students, like most of us, will stick to what they know.
- Some students are adamant that they do not like group work despite acknowledging the importance of learning to work collaboratively.
- Some students want to be able to test their understanding of the material without relying on anyone else' help.
- Students are reticent to create their own problems and prefer to focus on finite answers.

- Students are weary of investing more time and effort into a prerequisite course.
- Students express discomfort with grader subjectivity on open-ended projects.
- Grade optimization was the main focus for many students enrolled in this course and strategically-minded students will opt for the path of least resistance.

Ultimately, these findings show that even students who were interested in exploring applications of course content remained reluctant to be tested in a way that invited uncertainty in a way that might compromise their grades at a time of their degree where maintaining high grades seems more important than prioritizing their learning. Moreover, midterm project students were not immune to these incentives because they, too, reported that their investment in the second half of the course dipped as a result of grade-based optimization. "We hate this system that we are trapped in, but we don't know what our cage looks like because we have never seen it from the outside." (Gore Vidal, 2004, as cited in Denzin & Giardina, 2016, p. 43)

Institutional Impediments to an Evaluation of Assessment

As I mentioned in the introduction, this research functions at two layers of analysis. In its primary capacity, it serves as a means to examine the pedagogical and logistical limits of active learning at scale by investigating the implications of adapting an introductory physics course to satisfy the relational and exploratory learning needs of freshmen Life Sciences students through the creation of instructional and assessment approaches that promote collaborative learning and self-directed inquiry. At its core, however, this research seeks to underscore and question the epistemological tension inherent to the institutionalization of learning by examining the effects of introducing open-ended inquiry into the purview of risk-averse students who have long been rewarded within a highly prescriptive educational system. This understanding is based on the simple premise that the type of learner we are cultivating is determined by the way in which we score the learning process.

Points of friction within a mechanical system reveal underlying dynamics at play. Similarly, points of friction within a student's experience with formal education expose underlying tensions in the educational system that are often discounted as little more than an indication of a student's ability. When explored further, however, these tensions often reveal incongruities that are worthy of much more attention. Arguably the greatest point of friction within standardized education, for both students and teachers, comes at the point of evaluation.

The findings of this study are clear—students are intelligent actors—even if they can articulate all the numerous reasons why a group project-based assessment would be beneficial to their learning, many remain adamant that, if given the choice, they would choose a traditional test every time. This insight is at odds with the prevailing notion that better education can be gotten at by better means of teaching. Remedial efforts such as clearer rubrics, specifications grading, and more robust grader feedback will not go very far unless there is greater symmetry between the ways in which students are being taught to learn and the ways in which their learning is being assessed. If students were selected for a spot in higher education according to criteria that solely rewarded the product of learning then, despite good intentions, these same students will emerge from one more alternative course only to have to readapt to a larger system that continues to reward the product over the process of learning.

Furthermore, it must also be acknowledged that the introduction of learner agency and self-direction into the requirements of formal education at the graduate-level, when, up until that point, students had been assessed according to opposing evaluative standards is pedagogically irresponsible on the part of the education system. At the very least, it is confusing to the learner who must quickly adapt to a very different educational paradigm. The consequences of this double bind have an undoubtedly negative effect on the quality of a student's research capabilities and on their long-term desire to pursue academic careers, especially when presented with more lucrative and less institutionally guarded alternatives. Allowing younger students to be exposed to forms of assessment that reinforce self-directed learning earlier on in their degrees has the potential to mitigate both the paralyzing fears that many graduate students face when thrust into the depths of self-guided scientific research and may serve to retain a higher percentage of graduate students who jump ship, with or without their degree in hand.

> "An end which is the child's own carries him on to possess the means of its accomplishment." (Dewey, as cited in Tampio, 2019, p. 81)

Implications of Process-Oriented Instruction and Assessment in the Age of Generative Artificial Intelligence

In the years since this data was collected, the technological landscape has undergone a seismic shift. The advent of generative artificial intelligence software that is highly efficient, effective, and accessible has ushered in a slew of new variables into the ways in which student learning is being assessed at every level of the formal education system. Institutions of higher learning are, notoriously, slow to adapt and this new technological playing field is mushrooming at a such a rapid pace that schools are being left with more questions than they have answers to. Needless to say, this issue is not limited to schooling, but the effects of generative artificial intelligence that can pass let alone the Turing test but the bar exam lead us to question the very purpose of the education system.

AI, as a tool, is not a panacea of learning but it is also not an outright impediment to the learning process. AI helps its user to understand *that* something happened rather than what choices went into the process of coming to a conclusion. Even more crucially, AI does not help its user to understand why something does or does not work because it obfuscates the algorithmic logic through which a set of decisions were made. However, AI is a powerful tool that is now in the hands of anyone with access to the internet. When students engage with time from a scarcity mindset, the need to find the most efficient way to get to an answer becomes that much more compelling. Generative artificial intelligence platforms that dish out coherent, synthesized, formatted answers to word-based prompts are the most time-saving tool available. As such, it is an easy way for learners to outsource the effort involved in the parsing, processing, and digesting of information. The process of learning involves hard work. To have a tool at one's fingertips with seemingly inexhaustible, well-formulated answers is an almost irresistible temptation. It is this lure to focus on the finite rather than the abstract that, from my vantage point, robs the user of their learning potential.

Deep-level learning requires navigating complexity by engaging with abstraction. It is this process which one must, ultimately, come to on one's own that nurtures a learner's curiosity and empowers them to build upon their endlessly incomplete understanding. Moreover, it is the creation of one's personal lens of interpretation that allows the learner to ascribe meaning. A system that enables a student to coast through their degree without having had to digest complex, unrefined, abstracted information is a system devoid of meaning. Ultimately, it is the way we come into an idea, ponder it, and apply it, that allows us to understand what we are doing—its beauty lies in its inefficiency. In opting for short-cuts to an answer, a student is undercutting their own ability to come to understanding.

The group project midterm outlined in this research provided students with the space to gain an appreciation of the scope of what they did not understand in a context they, themselves, had chosen to investigate. In finding answers to their own questions, they entered into the process of learning where the solution to one question unlocks a myriad of new, better questions worth asking—the ouroboros of inquiry:

> Once we saw that the neuron is very similar to a circuit, there are so many connections we can make. And it just helped [us] understand how circuits work better because we can compare it to how a nerve works. And if we understand that, then we can kind of understand how the circuit works. And then we kind of discovered how the myelin sheath is like an insulator. And then we looked at insulators and conductors. And then I vividly remember we were trying to figure out a way to make the question more complex. And so I was just looking at the circuit that we had drawn up the nerve. And then we were trying to come up with a solution or a new drug for MS.

Hence, cultivating one's heuristic learning process might best be described as "failing forwards" (Peschl et al., 2020, p. 2). Familiarizing oneself with this trial and error method of "discovering why the 'stupid' errors are 'stupid'" (Davis, 1976, p. 64) allows the learner to develop specialized knowledge while retaining the generalist's sense of boundless curiosity. It is in refining the scope of one's interpretative lens that the learner comes to ask ever better questions.

If anything, this new technological age provides us with an open invitation to include greater transparency of process and collaboration into the formal education system. To ignore this need is to ignore the next generation's ability to engage in sound reasoning. Thinking is a process that, like a muscle, needs to be worked in order not to atrophy. It is a process that necessitates tension and resistance. A learner needs to be able to feel lost and to get things wrong because it is in recovering from one's mistakes that the learning happens. Smoothing and sanitizing this process is a mistake that the education system cannot afford to make. This new technological frontier offers us a broad new exploratory horizon but greater access to unconstrained exploration also entails a higher probability of making mistakes, especially when such tools are in the hands of novices.

At its best, education—the combination of instruction and assessment—has the potential to invite a learner into the process of understanding how to learn. In order to achieve this aim, it is the demonstration of a learner's process through an idea as well as their finished solution that should be rewarded. Although this shift in the landscape of learning incentives in higher education may end up being subverted by many of those who encounter it, the following student quote serves as evidence that, even for students in a highly prescribed educational system, the introduction of an assessment style that encourages collaboration and self-directed exploration can have its intended transformative effect:

> It was challenging and daunting and a lot of work, but engaging and thought-provoking and rewarding. I've been very frustrated for a long time with the way evaluations are typically run. There are way more benefits to a group project than a written test, in addition to it being a better evaluation of one's understanding and I wish more people saw that. I probably won't remember how to use Kirchhoff's laws or how to solve for the currents in a circuit next year, but I will take with me the ability to think outside the box, to problem-solve, and how to connect concepts, as well as a better appreciation for electromagnetism as a whole. That's what education should be about.

Directions for Future Research

As mentioned in my methodological context section, the findings in this study do not represent the full extent of the data I have collected over the last five years. The accounts of the student experience gathered from this particular intervention were, however, the best way in to address a deeper philosophical reckoning at the intersection of lofty pedagogical aims and the reality of economies of scale coupled with highly grade-incentivized students.

The pathway forward in this research presents many new interesting and challenging angles. The educational and political climates of the societal context in which this university exist are currently at significant odds. I look forward to the possibility of further exploring how the pedagogical aims of a research-intensive university will be impacted as populist ideologies raise an increasingly pervasive sense of doubt in the value of higher education.

One particular pedagogical ambition still remains: the implementation of oral presentation-style exams at scale for freshman-level students. This type of assessment would require students to develop their own concept-bridging problem and be asked to explain it to an invigilator who would then probe their understanding, similar to the format of a dissertation defense. This goal has represented the pinnacle of process-oriented learning to me for some years. Luckily, the potential for a two-part collaborative final exam in the coming year may lead my research one step closer to this ambitious aim.

At a more local level, as my university undergoes an institution-wide process to revamp its assessment policies, how will the austerity produced by looming provincial budget cuts to English-speaking higher education thwart endeavors to emphasize the process over the product of learning?

Contributions to Knowledge

What this research has contributed to the field of Physics Education Research is to provide answers to a question that has often been overlooked by educational researchers: What is at stake when novice students are given opportunities to pursue project-based inquiry-guided assessment in a large-scale freshman physics course?

Rather than simply showing how a pedagogical intervention has played out in student grade-based achievement, it relocates the line of inquiry towards the internal logic of the educational system as a whole. In doing so, this study shows that you can, in fact, provide students with incredible exploratory learning opportunities but the majority will still continue to navigate an assessment structure in a strategically grade-conscious way that will take away from the value of the intended exploratory flexibility. It is, therefore, the broader system that needs to be reevaluated such that individual efforts by educators can have a lasting impact.

In essence, this research serves as an invitation into a reimagining of what is possible at scale for a non-physics student demographic by presenting arguments in favor of marrying quantitative and qualitative assessment for all students, no matter their disciplinary background or level of content mastery.

> We tend to talk about education as a simple process of acquiring knowledge. On this view, education is about the transfer (or more accurately the copying) of information between the brains

> of teacher and learner. […] Learning, by contrast, changes the learner herself. We don't simply emerge from education with more things in our heads, but with different heads on our shoulders. We're given new habits of thought, and familiarized to new ways of seeing the world which force us to revise things we've believed without even noticing them. (Stokes, 2016, p. 94)

A Graduate School Metamorphosis

When I first applied to this graduate degree in Education and Society, I was rejected. On paper, there was no reason to admit me to a graduate program—my grades were not indicative of a student who would be able to excel within the higher education system. The only redeeming feature of my application was a collection of four letters written by faculty and staff I had built a personal relationship with during the period that followed my return to finish my undergraduate degree. These letters told the story of the kind of learner I was, not of what I had to show for it. The letters vouched for my character, rather than my demonstrable intellect.

Even with these four heartfelt letters, explicit support from my prospective department, and two co-supervisors lined up, my appeal fell on deaf ears. It was not until over a week into the start of what would have been my first semester that I summoned the courage to try, one last time, to ask for a chance to continue my studies as a graduate student. It was this email, this last attempt to advocate for a seat at the table, that is the reason I was able to pursue the research outlined in this thesis. My message included a note that I think was as prescient then as it is today:

> Now, more than ever, the need for environments and structures that engage student learning in more meaningful ways will be a challenge for our society over the coming decades. I would like to continue contributing to this worthwhile and challenging endeavor. If I have learned anything from the pandemic situation, it is the importance of conventional institutions as anchors of stability in times of change. I understand that my interests in alternative learning need to work with and within existing structures in order to be of service to the larger community.

I present this excerpt as palimpsestic evidence of my express intention to continue growing within the formal education system. The completion of this graduate degree has been my version of the 'doctor heal thyself' adage. It represents my own version of Jonathan Rose' account of the British working classes' struggle to forge with their own hands the secret they could not find in their given condition. (2001) And in pursuit of this healing, I have learned to think. “Thinking,” writes Hoveid, “is something more than remembering what has happened. Thinking is a form of opening towards the future.” (2019, p. 90) It is an act that demands hope: “People learn by experience… People must touch and taste an alternative way of doing things, they must however briefly live inside that hope, in order to come to believe that an alternative might really come true.” (Staughton Lynd, 2009)

Mere epistemic disobedience is not enough—learning requires the learner to transform. Learning entails metamorphosis. One reading that stood out during this degree led me to a sentence that, I think, best captures the terrifying risk involved in transformative learning: “Why would you risk undergoing a process that might destroy the foundations of who you take yourself to be?” (Stokes, 2016, 94) I am not the same person I was when I started this degree. I am a stronger, more resilient thinker with the discipline needed to live with complexity without becoming defeated by it. My experience as a graduate student has allowed me to build an interpretative matrix more adept at observing and making sense of the world around me.

The way that I have gone about this transformation is through reading. The reading I am referring to is described by Maryanne Wolf as ‘solitary communication’ (Klein, 2023). It is a slow and deliberate way of engaging in active thought by exposing oneself to the vulnerability of embodying someone else’ way into an idea. And, in doing so, it allows the reader to develop their own voice. Reading in this way strengthens one’s heuristic process of learning. The reading that strengthened my heuristic process was not the typical, academic reading that is often covered in formal education. However, from the readings I was exposed to during my courses, there is one paper that stands out: Michael Dumas’ *Beginning and Ending with Black Suffering*. It delved into impossibly difficult, cerebral content but with a form and style that elevated it to what felt like an almost artistic experience. It provided a model of what was possible that I desired to emulate.

Perhaps the greatest gift of an education is the permission to try to improve.

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Appendix A: Sample Recruitment Script

To all PHYS 102 students,

Rebecca Brosseau, a Masters student in the Department of Integrated Studies in Education, is conducting research on the impact of alternative modes of assessment in PHYS 102 this semester. The objectives of this study are to assess the impact of this semester's alternative midterm evaluation approach on students' motivation, overall performance and long-term retention of course content, and preparedness for a future in scientific research.

Participation in this study is voluntary and your identity as a participant will remain confidential during and after the study. This study is composed of an online survey, a follow-up virtual interview and a multiple-choice retention test. In total, we expect full participation in this study to take approximately one hour over the months of April and May. Rebecca's supervisor, Professor Nikolas Provatas, will not have access to identifiable data from this study.

If you accept to participate in this study, please fill out the following form: https://forms.office.com/r/wXQjUBs4S4

If you have any further questions please get in touch with Rebecca Brosseau (rebecca.brosseau@mail.mcgill.ca). The proposal for this research has been reviewed by the Research Ethics Board (REB file number 22-03-113) and has been found to be in compliance with McGill University's ethics policy.

Thank you for helping to improve this course for the next generation of students!

Appendix B: Participant Consent Form

MS Forms Participant Consent Form + Student Feedback Survey: https://forms.office.com/r/wXQjUBs4S4

Principal Investigator: Rebecca Brosseau, MA Integrated Studies in Education, rebecca.brosseau@mail.mcgill.ca, 514.654.1101

Co-Investigator: Peter El Khoury, BSc. Department of Microbiology and Immunology, peter.elkhoury@mail.mcgill.ca, 514.582.5115

Supervisor: Nikolas Provatas, Professor in Department of Physics, nikolaos.provatas@mcgill.ca, 514.398.4479

Purpose of the Study: PHYS 102 has recently incorporated innovative evaluation approaches. The objectives of this study are to assess the efficacy of these new approaches on students' motivation, overall performance and long-term retention of course content, and impacts on future academic pursuits. This provides guidelines for future directives into science learning and teaching and will inform further iterations of the course.

Study Procedures: 1. Students will fill out a consent form to determine their level of participation in this study. 2. All consenting participants will fill out an MS Forms survey to better understand their experience with their chosen midterm assessment style. 3. After the semester is over, consenting participants will take part in a follow-up interview on MS Teams as well as a multiple-choice retention test on MS Forms administered following the interview.

Participation: Participation in this study is entirely voluntary. At any point during the study, participants may decide to withdraw and retract their answers and/or participation with no implications or negative impacts. Participants may also choose to decline to answer any question or take part in any procedure from the study at any time and for any reason. Participants who agree to take part in a recorded interview may choose to turn off their video. In case of withdrawal, participants will be asked if they would like to retract and destroy any personal data collected. Participants will have up to two years to withdraw their data from this study. However, data collected from this study may be used in conference presentations and future publications prior to this two-year mark.
Potential Risks: There are no anticipated risks to you by participating in this research.

Potential Benefits: There are no potential benefits to the student participants. The choice to participate in the survey, interviews and retention tests will have no impact on course grades and all interviews and retention tests will be conducted after the course grades have been released.

Confidentiality: The researchers, Rebecca Brosseau and Peter El Khoury, will have access to identifiable data for a period of two years. All survey responses, interview recordings, and retention test responses will be stored on Rebecca Brosseau's McGill OneDrive account. The professor, Nikolas Provatas, will not be given access to identifiable participant responses, however, he will receive a list of students who participated in this study in order to provide the researchers with student grades at the end of the semester. Any communication with survey respondents to organize interview logistics will be sent through McGill Outlook accounts. A de-identified version of the study data will be shared with the course instructor, Nikolas Provatas, for the sake of course improvement.

Dissemination of Results: Results will be disseminated for an FSCI 398 project, a MA Thesis (DISE), internal McGill reports and presentations, conference presentations, and in peer-reviewed publications.

Questions: For any questions, feedback or concerns, please refer to Rebecca Brosseau (rebecca.brosseau@mail.mcgill.ca). If you have any ethical concerns or complaints about your participation in this study and want to speak with someone not on the research team, please contact the Associate Director of Research Ethics at 514-398-6831 or lynda.mcneil@mcgill.ca, REB file number 22-03-113.

Participant Consent

Please select "Yes, …" below if you have read the above information and consent to participate in this study. Agreeing to participate in this study does not waive any of your rights or release the researchers from their responsibilities. To ensure the study is being conducted properly, authorized individuals, such as a member of the Research Ethics Board, may have access to your information. Should you want to keep a copy of this consent, please print it now or save it on your computer. The researcher will keep a copy of your consent form.

1. First and Last Name

____

2. McGill Email

____

3. Do you consent to participate in a survey about your experience in PHYS 102 this semester?

- o Yes, I consent to participate in this survey.
- o No, I refuse to participate in this survey.

4. Do you consent to allowing your midterm and final grades in this course to be analyzed for the purpose of this study?

- o Yes, I consent to my grades being used for this study.
- o No, I refuse to have my grades used for this study.

5. Do you consent to participate in a recorded interview about your experience in PHYS 102 after the end of the semester?

- o Yes, I consent to participate in a recorded interview.
- o No, I refuse to participate in a recorded interview.

6. Do you consent to participate in a multiple-choice retention test after the end of the semester?

- o Yes, I consent to participate in a retention test.
- o No, I refuse to participate in a retention test.

Appendix C: Grader-Facing Midterm Group Project Rubric

Creativity

Does the question have an interesting real-world connection? Is it original and unique? Are there interesting connections between concepts learned in PHYS 102?

1 – the question is basic and has limited or no application to the real-world

3 – the question has some real-world application, but is generic (seems similar to most questions found in the course)

5 – the question is novel and innovative, it addresses a real-world situation and has creative connections made between concepts

6 – the creativity and innovation in the question exceeds what would be expected from a freshman physics course

Difficulty

Is the question the appropriate level of difficulty for the course? Is it as challenging as other questions shown by Dr. Provatas? If presented to the class, would it be too difficult for your peers to answer it? Or too easy?

1 – the question is far below or beyond the level of the course. Either students would be able to answer it easily, or students would not be able to answer it at all

3 – the question is near the level of difficulty expected for the course

5 – the question is perfectly matched to the level of difficult expected for the course

Integration of Course Concepts

Does the question show more than one course concept? Are the concepts integrated together such that they form one whole question (not one situation with part a) having one concept and part b) having another concept, unlinked)?

1 – the question only shows one concept

3 – the question shows multiple concepts, but they are not connected in the question

5 – the question shows multiple concepts, their relevance to each other is seen in the question, the concepts are linked together smoothly

6 – this question shows multiple concepts from both PHYS 102 and PHYS 101, they are connected together smoothly and in an innovative and creative way

Content

Does the content in the question have relevance to PHYS 102 and PHYS 101? Does the physics of the question make sense? Is the proposed solution correct?

1 – the physics in the question is either irrelevant to PHYS 102, or it (or its solution) is incorrect.

3 – the physics in the question is somewhat relevant to PHYS 102, however, there are mistakes in logic

5 – the question has physics concepts seen in PHYS 102, the reasoning throughout the question and solution is correct

Presentation

Is the question clear and well laid out? Is it easy to understand what the question is asking? Is its structure appropriate for the question (does it flow well given the content and the questions being asked)? Are there grammatical errors?

1 – the question is messy and disorganized, it's unclear or confusing what it is asking, the structure is not appropriate

3 – the question is somewhat organized; the structure is not the most appropriate for the question

5 – the question is clear and well-put, the structure of the question fits exactly the content and what it's asking, the question looks polished

Diagram

Does the question contain a useful diagram if applicable? Is the diagram clear, correct, or useful?

1 – it would be useful if the question had a diagram, but it does not, or it does have a diagram, but it is incorrect in reference to the question

3 – it would be useful if the question had a diagram, but the diagram given is unclear

5 - it would be useful if the question had a diagram, and the diagram given is a clear depiction of the question that would help when answering the question

Appendix D: Survey Questions

MS Forms Participant Consent Form + Student Feedback Survey: https://forms.office.com/r/wXQjUBs4S4

1. Which midterm assessment did you opt into?

- In-person midterm test
- Midterm group project

BRANCH A (for students who opted for the midterm test)

2. Which of the following statements best describes the reason(s) you chose to be graded on the multiple- choice test rather than the midterm group project? (Please select all that apply.)

I opted for the multiple-choice test because …

1. I'm most familiar with this assessment format.
2. I prefer to be tested individually rather than on a group project.
3. the grading rubric was more straight-forward than the group project midterm.
4. I lack confidence in my writing skills.
5. I prefer to be tested over a shorter timespan.
6. Other (please elaborate)

3. Rate the following statements on a scale of 1 to 5
(1: not at all; 2: very little; 3: somewhat; 4: quite a bit; 5: very much, N/A)

1. I chose to do the in-person midterm test because the midterm project requirements were unclear to me.
2. I made use of the midterm review session in preparation for the midterm test.
3. If given the option, I would have opted for both an in-person midterm test and a midterm group project.
4. I would have chosen the midterm project if I had been given the option to do it individually.
5. The practice problems provided in this course (CAPA, in-class problems, tutorial problems) gave me a clear indication of the expectations going the midterm test.
6. I believe that I perform to the best of my abilities under short, high-intensity testing conditions.
7. I have a strong preference for multiple-choice tests.
8. My preferred mode of studying for this midterm test included engaging with my peers.
9. I felt confident in my ability to do well on the multiple-choice midterm based on my experience in previous undergraduate courses.
10. In my opinion, the in-person midterm test allowed me to demonstrate the depth of my understanding better than a group project.
11. I am more confident in my ability to memorize course material than in my ability to apply concepts creatively.
12. Based on my experience with the midterm test, I felt confident in my understanding of the course concepts going into the final exam.
13. The feedback that I received from my midterm test helped me to clarify misconceptions that I had on the concepts I was tested on.
14. The feedback that I received on my midterm test helped inform how I studied for the final exam.
15. I find it more challenging to be assessed on applications of course content rather than theory.
16. I feel engaged as a learner when I focus on discrete conceptual problems rather than on their applications.
17. My interest in the course content was more focused on the theory rather than on the applications of electromagnetism.
18. If given the option, I would choose to do a group project at the end of the semester rather than a standard final exam.
19. I am interested in seeking out research-oriented environments (lab courses, independent research projects, etc.) during my academic career.

4. Based on your experience with the multiple-choice midterm test, what do you think are some of the learning benefits and/or disadvantages of a project-style midterm vs a multiple-choice test?

5. If you were to take this course again, would you opt in to the in-person midterm test or the midterm group project? Why?

BRANCH B (for students who opted for the midterm group project)

2. Which of the following statements best describes the reason(s) you chose to be graded on the midterm group project rather than the standard multiple-choice test? (Please select all that apply.)

I opted for the midterm group project because ...

1. I thought it would allow me more flexibility to learn the course concepts.
2. I thought it would allow me to better demonstrate my understanding in a low-stress environment
3. I thought it would allow me to self-direct my learning of the course concepts.
4. I was interested in the option to create my own concept-bridging questions.
5. I dislike multiple-choice tests and would choose any alternative assessment style that was not a multiple-choice test.
6. I prefer a longer time-frame to submit my work.
7. I prefer working on a collaborative project rather than on my own.
8. Other (please elaborate)

3. What concepts or chapters from the course did you choose to incorporate into the questions you developed?

4. Rate the following statements on a scale of 1 to 5 (
1: not at all; 2: very little; 3: somewhat; 4: quite a bit; 5: very much, N/A)

1. Before submitting my midterm group project, I had a clear understanding of the project requirements.
2. I attended the midterm project
3. My understanding of the course concepts improved thanks to the discussions I had during the drop-in sessions.
4. The feedback I received during the drop-in sessions motivated me to delve deeper into the concepts I implemented in my project.
5. Going into this project, I felt confident in my ability to build concept-bridging questions based on the concepts in this course.
6. This project helped deepen my understanding of how electromagnetism relates to other scientific fields.
7. This project helped deepen my understanding of how concepts from this course are interrelated.
8. My team chose to incorporate content related to our field of study in the questions we designed.
9. My interest in electromagnetism was piqued by the exercise of creating my own questions.
10. Applying electromagnetic concepts to real life scenarios made learning the course material more enjoyable.
11. The open-ended nature of this project encouraged me to research content beyond the scope of this course.
12. I feel more engaged as a learner when I am able to apply what I am learning.
13. In my opinion, I have a stronger grasp of the concepts I applied in my midterm project than I do of the other content from this course.
14. Going into the final exam, I was confident in my understanding of the chapters that I had applied in my midterm project.
15. My understanding of the course concepts improved thanks to the discussions I had with my project partner.
16. The work that I contributed to this project was done mainly by myself.
17. I enjoyed the independent exploration that was possible in this assessment style.
18. In my opinion, the independent exploration possible in the midterm project probed my interest in the course content.
19. The feedback that I received with my graded project helped me to clarify misconceptions that I had on the concepts I had applied.
20. The feedback that I received on my midterm project helped inform how I studied for the final exam.
21. If given the option, I would choose to do a second group project at the end of the semester rather than a standard final exam.
22. In my opinion, this assessment style allowed me to demonstrate the depth of my understanding better than a standard multiple-choice test.
23. I would have preferred to submit an individual midterm project rather than a group project.
24. I am interested in seeking out research-oriented environments (lab courses, independent research projects, etc.) during my undergraduate degree.
25. My experience with the midterm group project has increased my desire to pursue academic research during my undergraduate degree.
26. My experience with the midterm group project has made me more confident to seek out research- oriented environments (lab courses, independent research projects, etc.) during my undergraduate degree.

Open-Ended Questions

5. Based on your experience with this assessment style, what do you think are some of the learning benefits and/or disadvantages of a project-style midterm versus a multiple-choice test?

6. If you were to take this course again, would you opt in to the in-person midterm test or the midterm group project? Please explain why you would prefer this assessment method.

7. Do you have anything else to share about your experience with the PHYS 102 midterm project that has not been addressed in the preceding questions?'

Final Question to all survey participants

Do you consent to participate in a follow-up short interview and non-graded concept retention test at the end of May 2022?

- Yes, I agree to participate in the follow-up interview and retention test.
- No, I refuse to participate in the follow-up interview and retention test.

Thank you for completing this survey. We will be in touch with you if you consented to be contacted for a follow-up interview and retention test.

Appendix E: Interview Questions

GENERAL QUESTIONS TO ALL INTERVIEW PARTICIPANTS

1. Which midterm assessment did you opt into?
2. Why did you choose this assessment method?
3. What elements of this course (CAPA, tutorials, lectures, midterm option) were most beneficial to your learning of the course content?

QUESTIONS RESERVED FOR STUDENTS WHO OPTED FOR THE MIDTERM TEST

1. Did you choose to do the in-person midterm test because the midterm project requirements were unclear to you?
2. Did you attend the midterm review session in preparation for the midterm test?
3. If given the option, would you have opted for both an in-person midterm test and a midterm group project?
4. Would you have chosen the midterm project if you had been given the option to do it individually?
5. Did the practice problems provided in this course (CAPA, in-class problems, tutorial problems) give you a clear indication of the expectations going the midterm test?

6. Do you believe that you perform to the best of your abilities under short, high-intensity testing conditions?
7. Do you have a strong preference for multiple-choice tests?
8. Do you prefer to study for a midterm individually or by engaging with your peers?
9. Did you feel confident in your ability to do well on the multiple-choice midterm based on your experience in previous undergraduate courses?
10. In your opinion, did the in-person midterm test allow you to demonstrate the depth of my understanding better than a group project?
11. Are you more confident in your ability to memorize course material than in your ability to apply concepts creatively?

12. Based on your experience with the midterm test, did you feel confident in your understanding of the course concepts going into the final exam?
13. Did the feedback that you received from your midterm test help you to clarify misconceptions that you had on the concepts you were tested on?
14. Did the feedback that you received on your midterm test help inform how you studied for the final exam?

15. Do you find it more challenging to be assessed on applications of course content rather than theory?
16. Do you feel engaged as a learner when you focus on discrete conceptual problems rather than on their applications?
17. Were your interests in the course content was more focused on the theory rather than on the applications of electromagnetism?
18. If given the option, would you choose to do a group project at the end of the semester rather than a standard final exam?
19. Are you interested in seeking out research-oriented environments (lab courses, independent research projects, etc.) during your academic career?

QUESTIONS RESERVED FOR STUDENTS WHO OPTED FOR THE MIDTERM PROJECT

1. Before submitting your midterm group project, did you have a clear understanding of the project requirements?
2. Did you made use of the drop-in sessions to get feedback about your midterm project?
3. If yes, how did your experience in the drop-in sessions inform your project?
4. Going into this project, did you feel confident in your ability to build concept-bridging questions based on the concepts in this course?

5. How did this project impact your interest in the course content?
6. Did you struggle with the open-ended nature of this assignment? Please elaborate.
7. Did the open-ended nature of this project encourage you to research content beyond the scope of this course?
8. Did you enjoy the self-directed nature of this assignment? Please elaborate.
9. In your opinion, did applying electromagnetic concepts to real life scenarios make learning the course material more enjoyable?
10. In your opinion, do you feel more engaged as a learner when you are able to see applications of the content you are learning?

11. Did your understanding of the course concepts improve thanks to the discussions you had with your project partner?
12. Did you enjoy the independent exploration that was possible in this assessment style?
13. In your opinion, did the independent exploration possible in the midterm project probe your interest in the course content?
14. Do you find that you have a stronger grasp of the concepts that you applied in your midterm project than you do of the other content from this course?
15. Going into the final exam, were you confident in your understanding of the chapters that you had applied in your midterm project?

16. Did the feedback you received along with your graded project help you to clarify misconceptions that you had on the concepts you had applied in your project?
17. Did the feedback that you received on your midterm project help inform you on how to approach the final exam?
18. If given the option, would you choose to do a second group project at the end of the semester rather than a standard final exam?
19. In your opinion, did this assessment style allow you to demonstrate the depth of your understanding better than a standard multiple-choice test?
20. Would you have preferred to submit an individual midterm project rather than a group project? If so, why?

21. Are you interested in seeking out research-oriented environments (lab courses, independent research projects, etc.) during your undergraduate degree?
22. Did your experience with the midterm group project increase your desire to pursue academic research during my undergraduate degree?
23. Did your experience with the midterm group project make you more confident to seek out research-oriented environments (lab courses, independent research projects, etc.) during your undergraduate degree? If so, how?

24. Based on your experience with this assessment style, what do you think are some of the learning benefits and/or disadvantages of a project-style midterm versus a multiple-choice test?
25. If you were to take this course again, would you opt in to the in-person midterm test or the midterm group project? Please explain why you would prefer this assessment method.
26. Do you have anything else to share about your experience with the PHYS 102 midterm project that has not been addressed in the preceding questions?’

27. Based on your experience with this assessment style, what do you think are some of the learning benefits and/or disadvantages of a project-style midterm versus a multiple-choice test?
28. If you were to take this course again, would you opt in to the in-person midterm test or the midterm group project? Please explain why you would prefer this assessment method.
29. Do you have anything else to share about your experience with the PHYS 102 midterm project that has not been addressed in the preceding questions?’