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A Case Study of Physics Education at Regis University: Taking Physics Beyond The Classrooms

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A Case Study of Physics Education at Regis University: Taking Physics Beyond The Classrooms

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The Universe and Me

The common reaction when I tell somebody that I study physics is, "Wow, that's great. What made you choose physics?" My response has always been, "Do you want a short answer or a long answer?" When I tell them the short answer, "physics is an intriguing subject," nobody has ever been satisfied. What is physics? What is so intriguing about it?

1. The Cosmic Perspective

One goal of this study is to find ways to help introductory physics students become curious about the physics ideas that they learn in class. A question that many students must have as they pursue a bachelor's degree is, "how can my knowledge benefit myself and others?" To answer this question fully, one must know what his or her role in the universe is. I believe that physics is an indispensable part of the "cosmic perspective." In *Astrophysics for People in a Hurry*, Dr. Neil DeGrasse Tyson explains this term,

> we owe ourselves and our descendants the opportunity to explore—in part because it's fun to do. But there's a far nobler reason. The day our knowledge of the cosmos ceases to expand, we risk regressing to the childish view that the universe figuratively and literally revolves around us.[1]

[1]Tyson 2017

In other words, Tyson insists the pursuit of a greater understanding of "the cosmos" must continue for as long as humanity exists. He claims that we have to continue our efforts of exploring the cosmos in order to move forward as a civilization. The goal of this exploration, as Tyson implies, is to get rid of false perceptions of superiority. We are not greater than the universe. The universe is not greater than us although that might seem to be an obvious fact. This comparison does not make sense because humanity and the cosmos are not separate entities. "We do not simply live in this universe. The universe lives within us," Tyson says.

What excites me the most about learning and working in physics is being a part of something bigger. A great example is when Professor Hart played a short video of Tyson explaining the "cosmic perspective" in an astrophysics course; Tyson's voice made us all feel very special. We are a part of something greater, and it is our obligation to go out and make sense of where we come from, who we are. As an aspiring physics instructor, I hope every person who studies physics experiences this "cosmic perspective." I have always wondered what makes scientists like Neil DeGrasse Tyson, Carl Sagan, or Brian Greene such inspiring characters. The secret to these people's success, in my opinion, is not their rigorous physics backgrounds but a lifelong dedication to help people realize what it means to be alive, and physics is their language. Many physicists are passionate about exploring and sharing their knowledge to the world. How can we do it right?

Physics education research is not a new topic, and the "cosmic perspective" that many top physicists are advocating for has been around for centuries. In fact, many great physicists of the past also understood this deep connection between humans and the universe. I argue that every human has an unquenchable desire for knowledge even though some of us might not be aware of it. The reason why discoveries continue is because we are never satisfied with our explanations of natural phenomena. Physicists dedicate their entire life to scientific discoveries due to this desire for knowledge. One of the challenges that has always been on my mind is how to make this knowledge accessible to the common people. When Einstein published his work on general relativity, very few people truly understood his ingenious ideas. Regarding the importance of teaching, Einstein claims, "it is the supreme art of the teacher to awaken joy in creative expression and knowledge." Teaching, according to Einstein, is an art. There are no proven teaching techniques that work for everyone. The primary role of a teacher, therefore, is not to explain everything to the students but to ask questions that provoke curiosity and excitement, which motivate students to explore the topics in their own spare time and provide guidance and mentorship when needed.

2. Learning and Teaching Physics

I started learning physics when I was fifteen. After almost six years of studying the subject, my understanding of it has transformed many times. In ninth grade, in my very first physics course, my teacher told the class, "I can help you learn how to solve physics problems, but I cannot help you understand physics." Of course, my immediate response at that time was, "What kind of teacher says this on the first day of school?" Now that I have a deeper understanding of the complexity and beautifully chaotic nature of physics, I admit that there was some truth in what my teacher said. Perhaps, my teacher defined understanding of physics as the ability to comprehend and apply the knowledge. Though my high school physics courses provided me with physics knowledge, there were not enough opportunities for me to apply that knowledge in my daily life.

I have gone through three distinct stages in my physics training. I call the first stage the plug-and-chug stage. During my high school years, I thought of physics problems as puzzles where I had to gather all of the pieces and put them together. The second stage is the building-my-foundation stage. When I took physics courses during my freshman year in college, I was able to learn and practice the language of physics, which is mathematics, and its elixir of life, which is the logical reasoning process. Knowing the language helped me understand the logic behind the equations that I tried to memorize in high school. Learning the steps of logical reasoning also helped me think about the practicality of different physics ideas. Finally, the third stage might be called realization. After acquiring the logical reasoning abilities and understanding the physics concepts behind equations and problems I solved in class, I realized how relevant physics was to my daily life. Being able to draw these connections between physics and the world around me made learning physics much more meaningful to me.

It is important to be aware that each student will go through learning stages that are different from mine. However, I believe that being able to draw connections between physics concepts and personal experiences should be an important part of learning physics at all levels. Most people who have learned physics only spend a semester or two on the subject at some point in our lives; that is often not enough to fully understand the essence of physics, which is its presence in everything we touch, see, smell, and hear, if we do not take our physics knowledge beyond the classroom. In 2018, Abhilash Nair and Vashti Sawtelle published the results of a case study on how a life science student named Sam makes connections between the physics she learns with her experiences outside the classroom. In this study, Sam starts out as somebody who has very little interest in physics. However, being able to do experiments that are relevant to her personal interests and associating with friends who are excited about physics slowly change her mind. The researchers conclude that "students are capable of making connections to physics if there is sufficient support and intersection between their interests, coursework, and support systems."[2] The researchers identify "intersection" between "interests, coursework, and support systems" as the key to helping students see how relevant physics is to their life experiences. Nair and Sawtelle imply that a meaningful physics experience does not and should not come from in-class activities only; it is an "intersection" of all of the above components. One focus of this study is the integration of these components in introductory physics courses at Regis University, which I hope will provide further evidence for Nair and Sawtelle's claim.

3. The Learning Culture at Regis University

[2] Nair and Sawtelle 2018

This study will primarily focus on students who are in introductory level courses for two major reasons. First, most of these students are relatively new to physics concepts and have not had advanced training in mathematics. At Regis University, these students are already experiencing active learning strategies in introductory physics courses. Therefore, I will be able to see how these strategies help students develop a sense of what physics means to them. Second, introductory physics students come from diverse academic backgrounds, which brings more variety to the survey responses that I will collect.

At Regis University, every first-year student is presented with a question that they will attempt to answer during their study at the university: How ought we to live? The small but diverse community here allows each individual voice to be heard. Therefore, each student spends their time not only studying for their degrees but also exploring meanings in what they do and developing an appreciation for disciplines that are not directly related to their field of study. The commitment to high quality education is also emphasized in the history and mission section of the Regis University's website,

> Inspired by St. Ignatius Loyola's vision, Regis' mission is to educate men and women of all ages and faiths to take leadership roles and to make a positive impact in a changing society. We encourage our students to seek truth, live purposeful lives and attempt to answer the question: "How ought we to live?"[3]

[3] Regis University, n.d.

Regis educators envision for their students an ability to “make a positive impact in a changing society.” The statement also makes it very clear that students are able to positively impact the society not only through knowledge but also through exploring their societal roles. What makes the Regis community special, in my opinion, is how well-rounded our education is. During my four years of studying physics at Regis, I have experienced a self-transformation that I would not have had anywhere else. As a physics major, this study does not just include computational modeling or problem-solving skills. I am able to gain an appreciation for different art forms, philosophy, American literature, and many other disciplines. General knowledge in these disciplines helps inform my analytical processes, logical reasoning and thus make me a better physicist. As I recall the time when I started to be deeply interested in physics, I am able to see how I could use physics to stimulate positive changes in my community.

The unique culture at Regis brings various advantages and disadvantages to teaching and learning physics, which makes Regis a great candidate for this study. The small community allows connections between faculty and students to be built at a much deeper level than in many large physics courses at big universities. In my conversations with the physics faculty at Regis, I have learned that the faculty truly value building relationships with students. Quyen Hart, a former physics faculty member, identifies “mentorship” and “trust” as the two characteristics that make a physics education at Regis special. All of the faculty that I have talked to agree that a good physics education has to be personal. When “trust” is built and a mentor-mentee relationship strengthens, the faculty understands his or her student’s goals and reasons for taking physics. Even though the materials and curriculum are universal across all introductory physics courses, each student receives personal support from the faculty. With the help of the instructor, that student is able to customize the learning strategies to help achieve his or her goals in the course. Fred Gray, the department chair, believes that there are two major goals for an introductory physics course: to help students learn about "the building blocks of the universe" and to "plant the seeds" of curiosity. These two goals are equally important, and maintaining the balance between knowledge and excitement is not easy. What most physics faculty find difficult is that they can only offer a limited amount of support to each student while understanding physics requires the students to spend many hours outside the classroom sharpening their skills through homework assignments. Students can only appreciate and get excited about the "building blocks of the universe" only when they do the work assigned to them. The cultures at Regis and within the Physics and Astronomy Department create a unique learning environment for physics students, so a study on how physics education occurs inside and outside the classroom will yield interesting insights.

4. What Do I Hope To Find Out?

The goal of this study is not to come up with an alternative to physics teaching strategies that occur in a classroom but to combine these strategies with building learning communities outside the classroom. At Regis, a student who takes introductory physics courses will spend 5.17 hours per week in a classroom discussing physics topics, acquiring information and performing laboratory experiments to inform their understanding. In many other universities, there are also weekly discussion sections and lab sessions that are three-hour long. What seems to be not as obvious is that each student is also expected to spend much time on their own (ten hours per week in my case) to prepare for in-class sessions, work on homework problems, and study for exams.

As I reflect on my six years of studying physics, I have come to some of the most important realizations in years. One question that I asked myself consistently was, “Why do I study physics?” There might be a way to develop a sense of why learning physics matters early in introductory physics courses. In my case, being a part of the physics community helps increase my interest in learning physics and build my belief that I can make meaningful impact on the world with the knowledge and skills that I will gain as a physics major. My physics career took a positive turn when I became more involved in activities within the Regis University Physics and Astronomy Department; this is one of the motivations for my thesis. I have always wondered if being a part of a learning community outside the classroom is one the key components of a positive physics experience for introductory physics students. In physics education research, there is a long history of studies in teaching and learning strategies in the classroom, however only in recent years did researchers start studying how physics learning takes place outside the classroom. In this thesis, I will study ways in which learning communities form at Regis and their influence on students’ learning outcomes.

At Regis, our small community makes discussions and group work outside the classroom convenient. During my four years at Regis, I have never had to study for physics exams or struggle through a difficult homework problem on my own. During the lab sessions in which I serve as a teaching assistant, I also notice that students find people that they can work well with quickly, and after just a few weeks into the course, there are groups of students who interact and collaborate with each other very often outside the classroom. As I talk to these groups, I also find out that some of them usually meet every week to help each other on homework problems. As I work with these students in tutoring appointments and lab sessions, I cannot help but wonder how physics educators at Regis can leverage this unique culture to deliver a physics education that provides knowledge, builds analytical skills, and nurtures an appreciation for the physics philosophy. At Regis, students in introductory physics have already been collaborating in small groups. Understanding the ways in which students collaborate will be the first steps towards building a strong and supportive community where introductory physics students can learn from each other.

To come back to the question of why one should study physics, the most complete answer, in my opinion, comes from the difference between internal and external motivations. Internal motivation comes from the enjoyment of the learning process, while external motivation comes from grades, results, and outcomes. The education researchers Trolian and Jach summarize these types of motivation, writing that,

> Although both types of motivation have been associated with academic achievement, students who are intrinsically motivated are more likely to persist in the face of challenges (Boyd, 2002), experience academic integration (Clark et al., 2014), and have higher self-concept than those who are extrinsically motivated (Cokley et al., 2001).[4]

[4] Trolian and Jach 2020

In other words, students who are internally motivated are more likely to overcome challenges in the learning process and see the relevance of what they learn in their personal experiences. In Chapter 2, I will discuss academic motivation in the context of active learning strategies at Regis.

5. Components of This Study

The study includes three components that represent three different perspectives (students, faculty, and physics education research) on the thesis questions previously stated. My role in this study is to build a coherent narrative on physics learning and teaching culture at Regis, based on these three sources. During the time of this study, a global pandemic forced most colleges to move online. Therefore, the physics courses mentioned in this study implemented a hybrid model with both online and in-person modes of instruction. With these unprecedented circumstances, collecting data for the study was more difficult than expected. However, the observations and experiences shared by the faculty and students during this unique situation were highly valuable. Furthermore, the narrative will also reveal any connections between active learning strategies in the classroom and informal learning communities out-of-class. With a better understanding of how these strategies and learning communities are connected, I hope to inspire students and educators to improve their teaching for future introductory physics courses.

To collect student responses to relevant topics of the thesis, I designed a ten-question survey that probed student opinions on various aspects of the introductory courses and resources available to them outside the classroom. The physics faculty helped advertise this survey to the students in their courses. In addition, I also sent emails and messages to individuals who took introductory physics courses in the past and encouraged them to take the survey. The survey collected responses from 33 students, with 26 non-physics majors, five physics majors, and two students who were considering majoring in physics. However, all of the questions in the survey regarded their experiences in introductory physics courses. The survey responses were anonymous, which allowed students to be completely honest about their opinions.

The sample in this study was not a complete sample of students who had experienced introductory physics courses at Regis, either in the past or at the time of the survey. Since the selection process favored students who were taking introductory physics at the time of the survey, the sample was non-random. Another limitation of the student survey, caused by the pandemic, was that in-person interactions were more difficult, and learning resources were more limited than a typical semester. As a result, some responses are not generalizable to a typical semester when the main mode of instruction is in-person. However, my hope is that a consensus about how students collaborate outside the classroom will emerge as I connect the student perspective with the other two perspectives in this study. Though some responses may not reflect a typical semester, understanding student's experiences when in-person learning was less accessible sheds light on how much students value in-person interactions as they learn physics.

Since the faculty directly design the introductory physics curriculum, it is worthwhile to hear what strategies and aspects of the curriculum they think have been effective and improvements they wish to make in the future. In addition, the physics faculty offer meaningful insights to students' behaviors within the classroom and within their learning communities. Table 1 shows the faculty members of the Regis University Physics and Astronomy department that participated in the study.

Table 1			
Name	Title	Affiliation(s)	Date of Interview
Frederick Gray	Professor	Regis University Physics and Astronomy Department	September 29 2020
Jennifer Jarrell	Instructor	Regis University Physics and Astronomy Department	October 01 2020
Emily Haynes	Affiliate Faculty	Regis College Affiliate Faculty	October 02 2020
Quyen Hart	Senior Education and Research Scientist	Space Telescope Science Institute Regis University Physics and Astronomy Department	October 10 2020
Evan Tilton	Assistant Professor	Regis University Physics and Astronomy Department	October 13 2020

With each faculty member, I had a one-hour long conversation about their experience teaching introductory physics courses, various active learning strategies they had implemented in the past, and the changes they want to see in the future. Each faculty also offers observations and comments on learning behaviors of students that are specific to the Regis University community. These stories and insights form a narrative of how physics is being taught at Regis University, most of which I will discuss in the next chapters of this thesis.

Studies by physics education researchers around the US and the world are important for my thesis since they allow me to compare the learning and teaching culture at Regis University to those of other academic institutes elsewhere. These studies span different topics that I will discuss in my thesis such as academic motivation, active learning strategies, and informal learning communities. Therefore, they will provide evidence for the conclusions I make from student survey and conversations with Regis physics faculty.

Physics Education at Regis

When I was in high school, I enjoyed learning physics and thought I was great at it. Not until my first semester at Regis did I realize that I had been learning physics the wrong way for years. My lecture-based, information-focused high school education did not teach me to think about physics as a tool to solve real world problems. I learned how to memorize equations, solve textbook problems, and prepare for exams. Of course, learning physics this way had its own benefits. I knew very well how to break down a problem, identify a path leading to the solution, and decide which equations I should use. However, I struggled to draw connections between the physics I did in the classroom and my daily life.

Taking physics in college changed my mind. My first physics exam at Regis went horribly; I scored 48 out of 100. Even though the highest score in the class was below 80 out of 100, that was still the lowest I had ever scored on a science exam in my life. I knew exactly how to solve the problems and understood the physics perfectly well. The reason why I did so terribly was that I did not know how to put my thoughts down on paper. In high school, for any physics topic being discussed in class, I was taught that there were only a few types of problems that would be on the exams and homework. Therefore, learning how to solve these problems and some of their variations would be sufficient for maintaining an A in the course. The problems on my first physics exams at Regis required more logical reasoning and conceptualization than I had ever seen. In high school, I never learned how to solve problems; I learned how to memorize problems.

1. Learning Objectives for an Introductory Physics Course

After my first year at Regis, I soon found out that a good physics education has to allow students to be creative and, at the same time, acquire a sufficient amount of knowledge. Researchers at Massachusetts Institute of Technology and Utah State University have found that the goal of most physics instructors is to turn students into experts. Students, on the other hand, want to see how physics connects to the world around them before committing to the hard work of learning physics.[5] In a study that involves a lecture-styled calculus-based physics course, Perkins et al. found that 19% of the students said their interest in physics increased after the course and 45% said their interests decreased.[6] However, in a study of courses that allowed students to actively discuss how physics is relevant to their lives in small group and whole class discussions, Otero et al. found that 66% of students said their interest in physics increased after taking the course.[7]

Although most instructors I talked to believe that creativity and information are both necessary and should not be treated separately, they believe it is often hard to maintain the right balance between these two components in a course. There are many sources from

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[5] Pritchard et al., 2009

[6] Perkins et al., 2004

[7] Otero et al., 2008

which students can passively gain information when taking a physics course such as textbooks, homework, surveys, in-class assignments. On the other hand, creativity in a physics course comes from applying the knowledge and drawing connections between knowledge and personal experiences. At Regis, introductory physics students participate in discussions, group presentations, computational projects, and many other activities that allow them to express their views on physics topics and share their understandings with others.

The physics faculty at Regis agree on the importance of passive learning components of the course. However, there are different opinions on what role passive learning plays in a student's overall experience with introductory physics. Hart and Gray both believe that creativity and knowledge always have to go together. According to Hart, students develop many important skills when working together on homework assignments and working through hard problems will make students become better thinkers. Gray, in addition, believes that passive learning is the "skeleton" and active, creative learning is the "meat" of physics education. One goal of an introductory physics course, like introductory courses of any subject, is to build a foundation in knowledge and skills that benefit students in whatever career paths they choose. What complicates this goal is that introductory physics students come from various backgrounds and enroll in a physics course with different expectations. In my survey, 78.8% of students in introductory courses do not intend to take more college level physics. Only 15.2% of the students currently major or minor in physics, while the rest are undecided. According to the physics instructors, this diverse population of introductory physics students makes it difficult to ensure every student receives what he or she expects in a course. “We cannot make everyone happy,” Gray said.

Tilton and Haynes both believe that the boundary between excitement and frustration in learning physics is often blurry. According to Tilton, students in introductory physics must learn to “reject their gut intuition” and to “trust the math and physics laws” so that they could see how physics is relevant to them. Achieving this is extremely difficult as most students have been building up their intuition about human interactions with the natural world for over a decade and only have one or two semesters to learn how to “reject” it. From my conversation with Haynes, I have learned that one of the most important objectives Haynes sets for her introductory courses is to help her students acquire the skills and knowledge that allow them to continue transforming their intuitions even after the course has ended. Haynes, whose teaching style is inspired by her advisor, Carl Sagan, firmly believes that students need to “engage in a science investigation.” Haynes shared with me a story about Carl Sagan that has not been told before. In an astronomy course that she and Carl Sagan worked on, Sagan often got angry when students do not ask questions at the end of a lecture and think they had fully comprehended the physics. Sagan always emphasized the importance of asking questions to expand one’s knowledge. According to Haynes, Sagan often told his students, “Nobody is born with Fourier Transform in their heads.” Curiosity is, indeed, an important virtue in learning physics. Doing the hard work and struggling through hard problems is unpleasant. However, I have learned from the physics faculty and the physics education research literature that if students can see their curiosity grow and find opportunities to be creative during this arduous process that precedes excitement, they are still able to find joy in their work.

2. Active Learning Strategies

As an attempt to learn more about student's incentives in introductory physics, I have asked students to comment on topics that they enjoy learning about in their courses. What surprises me is how diverse the responses are. Students draw connections between physics concepts and their own experiences, which matches what the physics education literature describes.[8] Students love seeing how physics is relevant to what they encounter every day. In my survey, many students in my survey are able to see how physics is relevant to their fields of study. One student comments,

> [I like] concepts of forces around an axis because I am a Health and Exercise Science Major so that easily relates to the forces our muscles create so our joints can move around an axis.

A different student also tells me how they draw connections between physics and their major,

> I liked talking about sound waves and oscillators. I know they are different, but they really connected to what I learned in Chemistry and in Music. In a way physics branched these two areas of my study.

[8] Otero et al., 2008

The introductory physics courses cover a wide range of topics, which allow students plenty of opportunities to make such connections with their academic and life experiences. Some students are excited about learning physics simply because they like to challenge their intuition. One of the students writes,

> I enjoyed learning about angular momentum because it blows my mind how a force on a rotating object applied in one direction can lead to movement in a completely different direction. I also really enjoyed learning and discussing special relativity. Special relativity is also very unintuitive and mind blowing.

Some physics concepts are as “mind blowing” as they are “unintuitive.” As a result, “rejecting gut intuition” can bring joy if students can learn to appreciate the abstract nature of the physics laws. For some of the introductory physics students in my survey, what seems to make learning physics exciting is asking questions rather than finding answers.

Taken together, the student and faculty comments suggest that getting excited about physics and doing the passive work are not two separate processes. One can build up excitement and curiosity while learning important skills to continue investigating physics after the course has ended. At Regis, each physics faculty member has unique ways of identifying student incentives and helping them find motivation. Many instructors embrace teaching models that allow students to play the role of instructors through in-class activities. Hart shared with me that implementing such model brings many benefits. In some of her classes, students were asked to pick a topic that was of interest to them, gain an adequate understanding of it, and teach it back to their classmates. Therefore, the students who were presenters could bring personal experiences into the presentations as they had to describe the physics in their own words. Hart also observed that students in the audience often paid more attention and asked more questions when their peers presented.

My first encounter with this model was with Gray. In Gray's courses, students are asked to choose a topic from the curriculum that they find interesting and tell the class about it in ten to fifteen minutes. I still remember that my presentation was about resistors and how they are used in electronic devices. Even though I was very nervous about my presentation and the preparation took a significant amount of time, resistors somehow became my favorite electronic components. Being able to present a challenging concept to the whole class also made me believe that I could understand any physics concepts, no matter how hard they seem, if I were willing to put in the efforts. The benefits of using a flipped-classroom model are also evident in physics education research. Researchers at Harvard study data from ten years of implementing peer-instruction model in introductory physics courses designed for non-physics majors.[9] They conclude that peer instruction improves student mastery of concepts and quantitative problem solving and makes the courses "more welcoming to female students." Crouch et al. suggest complementing peer instruction with other active learning strategies and also believe that increasing student's motivation will also increase the effectiveness of active learning strategies.

Some physics faculty I interviewed believe that students can grow academic motivation as their understanding of physics improves. They observe, and the survey also

[9] Crouch, et al., 2007

shows, that many students in introductory physics at Regis need help from the instructors to find and maintain motivation. Tilton comments that the only academic incentive some students have is to get good grades and not necessarily develop an appreciation for physics. Their academic incentives are not what educators want, but the need of getting good grades is a good starting point to build up interest in physics for these students. There are several studies on how students' motivation changes during their college career. Ames, Anderman et al., and Kowalski all observe decline in students' motivation to learn over time.[10] Kowalski concludes, "students entered college significantly more learning- than grade-oriented. By the spring of the first year in college, however, students' learning and grade orientation no longer differed." There are several factors that affect students' motivation to learn. However, Halawah et al. identifies three major factors that affect student motivation in an introductory physics courses: they are personal qualities of the instructor, teaching methods, and classroom management.[11]

At Regis, physics faculty regularly implement and improve on these three factors. In their interviews, the Regis faculty express an interest in making learning personal to students, and all believe that making physics personal to each student allows them to grow both their curiosity and internal motivation. Hart always incorporates student presentations and creative projects into her courses at all levels. She shared how she designed creative

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[10] Ames 1992, Anderman, et al. 2002 as cited by Kowalski 2007.

[11] Halawah et al. 2011

projects for introductory physics students. In a trig-based physics course, Hart asked students to research the physics of any medical devices that were important for them or someone that they knew. One student told the class about a heat therapy device that she used regularly. That student realized that the physical laws she learned from the course helped sustain her life and the lives of many people with her medical condition. I asked Gray whether he has seen students who change the way they think about physics during an introductory course. Gray believes experience in introductory physics usually “grows” on students. In other words, given enough time, curiosity and excitement can lead to realizations.

Some faculty members at Regis allow students to design parts of the curriculum. Some faculty members believe that the introductory astronomy course allows them more flexibility to be creative with the course contents. Since this course mostly comprises non-science students, the learning objectives and starting points for them are different from other introductory courses. Jarrell believes that most students decide to take astronomy to fulfill their science core requirements, which shows that they have some general interests in the subject. Jarell often begins her astronomy course by asking students about topics that they have interests in and designs the course syllabus to cover as many of these topics as she can. Tilton sets explicit goals for his astronomy students as he hopes students to learn the skills and mindset needed to carry on science investigations beyond the course. In addition, he usually facilitates conversations about disputable topics in physics. As a result, students learn to recognize and use the scientific language. Haynes also has similar learning objectives for her astronomy students. In her opinion, students must learn to distinguish science from pseudo-science. Many students in introductory astronomy have little experience with physics and astronomy. Therefore, it is not easy for them to draw connections between what they learn and what they experience every day. Haynes is willing to have her students do activities that would not be in a typical astronomy curriculum to help them make those connections. In an astronomy course that she taught in the past, knowing that many students in her course believed in astrology, Haynes designed an activity to help students understand the main differences between astrology and science. Haynes asked her students to look up horoscopes from two days before that would provide prophesies for their yesterdays. Then, the students decided whether the prophesies were correct or not. Typically, Haynes described, only a few of the students had the correct prophesies. Through involving a subject that her students truly care about, Haynes made learning more interesting and personal to her students.

3. The Advantages and Disadvantages of Physics Education

Until now, we have learned how physics faculty maintain a balance between creativity and knowledge in their courses to help students nurture curiosity and grow internal motivation. The Regis physics faculty believe that education should be personal and each student experiences introductory physics differently. To determine whether there is a pattern in how students perceive this balance between creativity and pure information, I have asked students what they think is the most important in learning physics, and table 2 shows their responses.

Table 2	
What is Most Important?	Number of Responses (out of 33 total responses)
Homework (reading, weekly problems, surveys, and quizzes)	15 (45.5%)
Working with other students.	6 (18.2%)
Working one-on-one with the instructor.	5 (15.2%)
Self-study (through online resources such as YouTube, Khan Academy, or Google).	2 (6.1%)
Lectures and in-class activities	4 (12.1%)
Other	1 (3%)

The most popular response is homework (45.5%), which matches what physics faculty describe. However, the fact only 12.1% of the students believe that lectures and in-class activities help them learn physics is surprising. One possible explanation is that the lack of in-person interactions due to the COVID-19 pandemic has affected the quality of in-class activities. Though none of the students explicitly attributed their negative feelings to the pandemic, 72.7% of them mentioned having done no presentations in class. This statistic suggests that the pandemic has altered student involvement since presentations are a common teaching modality during non-pandemic semesters. With virtual platforms being used widely in physics courses, most students have told me that they have been struggling with self-motivation. Although some physics faculty believe there are positive changes that the pandemic brings, most of them describe how difficult it is to tell whether their students are actively engaged in the course activities. The above survey results also give us an idea of how students learn physics during this unprecedented time. Despite in-class activities being less interactive than usual, most students choose to work on homework on their own instead of seeking assistance from classmates or the instructor. It is possible that the reduced frequency of in-person interactions among students and the instructor make students feel less comfortable working with each other outside the classroom.

Physics faculty at Regis, based on their own teaching experiences, provide opportunities for students to be creative and learn actively in their courses. Most of them hope that students see some, if not all, of the physics concepts as relevant to their daily life and would find ways to make their physics knowledge useful. When it comes to applying what students learn in class to their daily activities, what kind of support from educators do they need? There are several studies on what should be done in introductory physics courses to make students become more motivated to learn physics. Trolian and Jach suggest that not all applied learning opportunities increase academic motivation,

> Some applied learning experiences, therefore, may be less connected to classroom learning and may not contribute to students' overall academic motivation in college, or they may lack sufficient interactions with faculty, which have been shown to be positively associated with student academic motivation (Trolian et al., 2016).[12]

Trolian and Jach imply that creating and maintaining academic motivation do not only happen within classrooms. Without "sufficient interactions with faculty," many students struggle to make connections between daily life experiences and physics. In addition, Trolian and Jach also brings up a very important point; not all learning experiences, such as internships, volunteering, public outreach events, "contribute to students' overall academic motivation." Once again, we see that meaningful and on-going conversations with the faculty and their peers are essential for students in introductory course.

At a small liberal arts college like Regis, in a typical semester, it is easier for students to build connections with one another, which, faculty opinions and educational research suggest, has a positive impact on students' motivation and effectiveness of an introductory physics course. All of the Regis physics faculty observe that there are disadvantages to teaching physics in a small environment. Gray, who has been at the Regis University for more than ten years, believes that time is the most limited resource at Regis, where faculty and students usually have several responsibilities. As a result, the support the faculty can offer also has a limit. In addition, lectures and laboratory sessions are not often long enough, which sometimes forces physics faculty to make tough decisions to cut

[12] Trolian and Jach 2020

short the lectures and in-class activities. Another disadvantage for teaching physics at Regis, according to Tilton, is that faculty do not have enough time to redesign courses and make creative changes regularly. Tilton also comments that he spends a significant amount of time on grading each week. Although it is important for students to get feedback for their homework, grading is not the most efficient use of faculty's time. It is clear that limited resources at Regis make teaching and learning physics challenging in these unique ways. Though the problem of limited resources might not be solved easily, there are ways in which we can leverage the advantages that a small community brings to enhance the quality of physics courses across the university.

When students take an introductory physics course, they spend more time learning physics outside the classroom than inside the classroom. However, at Regis, most physics learning activities that occur outside the classroom often happen without any monitoring or coordination. During our conversation, Tilton and I both agreed that there has not been an official learning community outside the classroom for students in introductory physics. Building such a community at Regis requires us to investigate the models currently being used by other universities to grow informal learning communities outside the classroom and understand the differences in learning cultures and student population between Regis and those universities. Although it is not guaranteed that models that are successful elsewhere will also be effective at Regis, they may provide a starting point for coordinating learning communities in a way that maximize the effectiveness of these communities.

Towards Building a Physics Community

Recently, I have realized that not seeking for help was one of the reasons why my first year as a physics student at Regis was such a struggle. At that point, I still believed that I had already taken introductory physics in high school, so there was nothing new I could learn at the college level version of this course. I was wrong, and it did not take me long to realize how much I did not know. When I realized that paying attention during in-class lectures was not sufficient to fully comprehend the concepts, I started to avoid working on physics homework alone. Every week, I would meet some of my classmates to work on our homework assignments together. What my friends and I found helpful was hearing different approaches to the same problem, which helped each of us identify the strengths and weaknesses of our logic very quickly. In addition, explaining a concept that I understood well to others often helped solidify my intuition of that concept.

1. How Do Learning Communities Form?

In my experience, the small classrooms at Regis help students identify people that they work well with quickly. Every week, during tutoring sessions, I often see the same groups of students working on homework problems together. There are usually three to five students in each of these groups. Many students with whom I have worked tell me that working in small groups helps them solve the homework problems faster. In the Fall 2020 semester, the COVID-19 pandemic has made it almost impossible to maintain the typical level of in-person collaboration. However, students are still finding ways to support each other. Table 3 shows how students on my survey respond to the question, “Do you collaborate with other students to work on homework or study for the exam?”

Table 3	
How often do you collaborate with other students?	Number of responses (out of 33 total responses)
Everyday	2 (6.1%)
A few times a week	15 (45.5%)
Once a week	8 (24.2%)
A few times a month	6 (18.2%)
Once a month	1 (3%)
A few times a semester or less	1 (3%)

Nearly half of the respondents on my survey (45.5%) collaborate with their peers a few times a week to study and work on homework problems. Furthermore, 54.5% of the students surveyed say that they would want to collaborate with their peers even more without the inconvenience of the COVID-19 pandemic. Students understand that collaboration outside of the classroom is important for their success in a physics course. However, there has not been an official gathering space for introductory physics students at Regis until recently.

In the Spring 2019 semester, some physics majors at Regis, myself included, decided that we could all benefit from weekly meetings where all physics majors could socialize and work on physics homework together. The demand for such a gathering space was high since upper division physics homework had always been more difficult and longer than introductory physics homework. We later turned these weekly meetings into an official student club called the Physics Collaborative Community (PCC). When I became the president of PCC in the Fall 2019 semester, the club worked very hard to encourage introductory physics students to come and work on their homework problems with the club members. We all believed that any physics student could and should take advantage of this community. Since introductory physics students were already collaborating in groups outside the classroom, we all thought that doing so in an official gathering space would allow students to support each other more effectively. However, after a few semesters, I saw very little participation in the weekly meetings from introductory physics students. There might be three possible explanations. First, the club started as an exclusive space for physics majors and minors. Although we became open to all students taking physics courses later, most students who were having a hard time in introductory physics might have found it intimidating to be in a room full of people who loved physics. Second, due to time conflicts among members, we could only organize weekly meetings after 6 pm, which I discovered to be inconvenient for many other students who wanted to participate.

Third, the club was not widely advertised among introductory physics students. We only advertised the club to all physics students once at the beginning of the Fall 2020 semester. Although the PCC's success was limited, I learned a lot about the impact of a learning community on physics students from the experience. Most of the regular participants of the clubs find it useful to brainstorm through difficult physics problems together. The small events and lecture series we organized helped our members learn about many ways that physics could be used to solve real world problems.

There is evidence of the positive influence of informal communities on student's learning outcomes within physics education research. A study by Zwolak et al. shows that students who are actively engaged in both in-class and out-of-class networks are more persistent in introductory physics courses than those who are not.[13] Researchers from Florida International University use data from their informal Physics Learning Center (PLC) to understand the 400% increase in the number of physics majors over eight years.[14] Results show that students' participation in the PLC depends on two variables: major and frequency of attendance per week. Students who major in physics or attend the PLC regularly build very strong connections with other students, which lead to more interest in learning physics. Furthermore, these researchers also find that participation and the growth of student network do not depend on gender and ethnicity. Nainabasti et al. studied small

[13] Zwolak et al., 2017

[14] Brewe et al., 2012

groups of introductory physics students in two semesters (30 students in the fall and 26 students in the spring) and show that collaborative habits are formed during in-class learning activities, and these habits, which can be positive or negative, stay with the students regardless of who they work with.[15] These studies tell us that it is worthwhile for physics departments to invest in informal learning communities. However, Brewe et al. caution that it is difficult to measure the effectiveness of these learning communities without intensive investment of time and effort.

2. Collaboration in Learning Physics at Regis

The reduction of in-person interactions during the COVID-19 pandemic likely impact survey responses. However, with in-person interactions being more inconvenient, students are able to identify what they want from a learning community outside the classroom much more clearly. The survey asks students to identify obstacles that were preventing them from collaborating with their peers and what would make collaboration more appealing to them. Most students explain ways in which online learning has affected them. The majority of these responses mention lack of communication and collaboration due to not interacting with peers in person. One student comments,

> COVID has made collaboration hard because we never meet our classmates in real life. All I see about my classmates are their names, and sometimes faces during breakout rooms. Therefore, it is hard to find people to collaborate with.

[15] Nainabasti et al., 2015

Some students are not comfortable interacting with others virtually, and some find the online format of the courses distracting. Most responses agree that it is "hard to find people to collaborate with" when classes operate fully online.

Regis physics faculty have had to make drastic changes to their courses when courses are required to move online. Gray observes that the class attendance has been almost always a hundred percent. However, the energy level among students is much lower. Jarrell, on the other hand, comments that her courses rely on students helping each other out and working together inside and outside the classroom, which have been much more difficult due to the pandemic. Both Gray and Jarrell agree that an important component of their courses is the non-physics or informal conversations they could have with students in an in-person setting. According to Gray, it is hard to have side conversations to understand how each student is doing and support him or her sufficiently. Jarrell tells me that conversations on Zoom are not as "organic" as in-person conversations due to technological difficulties and general discomfort of communicating on Zoom. Jarrell also describes how much the dynamic of in-class conversations has changed, "instead of hearing little bits from lots of people, I hear lots of stuff from very few people."

In a research that compares two models of physics instruction, lecture-based and interactive science learning environment (ISLE), researchers at California State University, Chico (CSUC) and Florida International University (FIU) find a strong correlation between in-class activities and students' involvement in collaborative communities outside the classrooms.[16] Researchers believe that the ISLE model provides multiple collaborative opportunities through "assembled class discussions and review sessions" and also introduces "multiple channels for students to get to know each other and build relationships with each other." The interactive and collaborative structure of the introductory physics courses at FIU greatly enhances involvement in informal collaborative groups outside the classroom. The results of this study show that,

> At the beginning of the semester, out of 26 enrolled students, 19 (73.1%) were reported working with 2 or fewer classmates. After the semester, this number dropped to 1 (3.8%), and 12 (46.2%) students were reported by 19 or more of their classmates.

The ISLE model at FIU allowed the learning communities to grow throughout the semester, and half of the students enrolled in the course work together closely at the end of the semester.

The results from this study also match what I have learned from the reactions of students and faculty members to the changes during the COVID-19 pandemic. They also show that there is a strong connection between in-class collaboration and out-of-class collaboration. Therefore, it is necessary to consider collaboration both inside and outside the classroom as we find ways to help learning communities grow. In order to have an effective learning community outside the classroom, we must start from what is happening inside classrooms. As described in the previous chapter, physics faculty at Regis have

[16] Yang et al., 2014

strategies to enhance the quality of in-class activities. There are some strategies that I have found to be effective in promoting collaboration inside and outside the classroom at universities across the US, some of which I will share in the next section. Continuing to improve active learning strategies is an important part of growing collaborative learning communities. The other part of growing these communities should come from resources that are available to students outside the classroom. At Regis, the three main resources that are available to students outside the classroom are professors' office hours, tutoring services, and their peers. Table 4 shows how often students take advantage of office hours and tutoring services.

Table 4	
How often do you take advantage of office hours and tutoring services?	Number of responses out of 33 responses
A few times a week	5 (15.2%)
Once a week	6 (18.2%)
A few times a month	6 (18.2%)
Once a month	1 (3%)
A few times a semester or less	15 (45.5%)

According to the survey, nearly half of the students (45.5%) who responded only visit their professors during office hours or schedule tutoring appointments a few times throughout a semester. This result matches my personal observations. After a few semesters as a tutor, I have observed that out of more than a hundred students taking introductory physics each semester, only a small number of them visit the math and physics suite regularly for tutoring or appointments with their professors. According to the survey respondents, there are two main reasons that prevent students from attending tutoring sessions and office hours. First, some students experience time conflicts. Time is a scarce resource for students and faculty at Regis. Some students explain how helpful their professors or tutors are but cannot find time to meet with them more often. Second, some students find collaborating with their peers more convenient and believe that appointments with tutors or professors could be "intimidating." However, all students who use these resources agree that they yield positive learning outcomes. One student shares how they have taken advantage of collaboration outside the classroom,

> It's awkward at first to gather with a group and study, everybody can be occupied or not interested. But when we spend more time together in class and get to know each other we are able to communicate and be comfortable with each other. To make this [collaboration outside the classroom] more appealing is to have a group chat or Slack to chat. Another way is to gather at a certain day and time once a week or month.

Another student describes what are helpful for them when collaborating with peers outside the classroom,

> I like working with other students and find physics is always a lot easier to understand when you can just talk through things with people when you get stuck. I usually am really close to the answer and just need a little push to help understand what I know from the problem that I'm forgetting about.

Nearly half of students on my survey (45.5%) collaborate with other students a few times a week, and only 15.2% attend office hours and tutoring services at the same frequency. This discrepancy suggests that these students are more comfortable collaborating with each other than seeking for help from professors or tutors. Although the number of participants in this study is not large enough for this observation to be generalizable to all introductory physics students, it provides insight on how out-of-class collaborations should be developed. A student-centered learning environment has been developed at Florida Intentional University (FIU) for many years, and it has helped them grow the size of their physics department by many times. The main difference between Regis and FIU, which is also one of the biggest challenges for physics at Regis is limited resources. When some other physics majors and I were growing our physics club (PCC), we understood how much time and effort it took to develop a strong learning community outside the classroom. We had to find funding for events, invite guest speakers, promote the events, and stay in touch with professors and members regularly. Each of us was very busy with our academic and non-academic responsibilities, and the professors were even busier. We all wished to grow the physics club much bigger to provide students an environment to learn and connect with each other, but none of us had the time and energy required to do so.

3. What Changes To Make?

In physics education research, there are several proven strategies to stimulate collaborative learning communities, some of which might be useful at Regis. In my conversations with physics faculty, I discussed ways in which homework assignments can be different. Most of the faculty believe that working through homework problems is important to learning physics but are open to ways that homework can be structured differently. Stacy Godshall, a professor at The United States Military Academy in West Point, NY, researches a new method for assigning and grading homework, which she calls the phased-array homework (PAH) method.[17] The idea of this method is simple. Students are allowed two attempts on a homework assignment. Students first attempt to solve the homework problems before discussing the relevant materials in class. After the first attempt, if all of their solutions are correct, they can turn in their assignment for 100 percent of the available score. Otherwise, students receive feedback from instructors and their peers. If they turn in the assignment without redoing the incorrect solutions after the first attempt, they can only earn up to 30% of the available score. Students who decide to correct their mistakes during the second attempt can earn up to 90% of the maximum points of the assignment. According to Godshall,

> From the survey results, 88% of the cadets were more confident in solving physics problems as a result of the PAH process. 85% felt that the process assisted them in understanding the material; 83% were more relaxed about the homework grade and more motivated to solve physics problems; and 86% were satisfied with the process.

[17] Godshall 2011

These results show that the PAH process encourages students to learn from their mistakes, which leads to more confidence, motivation, and deeper understanding of physics concepts. These are the goals that every physics instructor sets for students. The PAH process mostly encourages students to work with their peers and the instructor outside the classroom to review their homework solutions after initial feedback, which is something that students should do anyway. Of course, some will argue that implementing such a model at a university where time is an extremely scarce resource will place extra burden on professors. However, the process relies on students correcting their homework and submit their solutions either after the first or the second attempt. Therefore, the amount of time an instructor spends on grading the homework and providing feedback does not change. The amount of time a student spends on doing homework does not change either. The only difference is that students work on their homework in phases. With the PAH process, students have an incentive to work with their peers and the instructor after the first attempt on the homework. In addition, the first attempt on the homework takes place before the relevant material is discussed in class, so students start working on their homework early instead of waiting until the day before the deadline.

In addition to adjusting the grading scheme, there are other components of the homework that we can modify or improve on. At Regis University, each course is accompanied by an online space where the instructor can conduct online surveys, discussions, and post any important information for the course. Most physics faculty are taking advantage of this online space to assign online surveys that are due before lecture sessions each week. These assignments implement just-in-time teaching strategy, where instructors use students' responses and feedback to prepare for the in-class lecture. The survey responses are helpful for faculty as they can find out how much students understand the topic that will be covered in class and whether there are any parts that the vast majority of the class cannot get a good grasp on. I personally enjoyed doing these surveys when I was an introductory physics student as I could ask the instructors longer questions that would be inappropriate to ask during a lecture. Just-in-time teaching has been shown to improve students' understanding of introductory physics concepts in large physics classrooms.[18] Though this strategy is not widely studied in classroom settings similar to that of Regis, many physics faculty who have implemented just-in-time teaching agree on the benefits it has brought to in-class discussions and lectures. The online space that Regis assigns to each course is a resource that educators and students have been utilizing, and I always wonder what else we can do to utilize this great resource.

In 2018, Myers and her colleagues published results from a research on using an online discussion forum in a calculus-based introductory physics course.[19] In this course, the instructor organizes small weekly discussions for students to engage with each other, known as "anchor tasks." In addition, students are also encouraged to initiate discussions on any random topics, known as "non-anchor tasks." Students are awarded up to 5% extra credit on their final grades for participating in these online discussions. The results of this

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[18] Formica et al., 2010

[19] Myers et al., 2018

research show that “informational” and “scaffolding” statements are most common in these discussions. In other words, most students often respond to a physics question that their peers have or make non-physics comments in these online discussions. There are two significant conclusions from this study. First, anchor tasks yield a higher frequency of scaffolding and responses to questions, while non-anchor tasks yield a higher frequency of questions, reflections, and informational statements. This observation is extremely helpful to physics faculty as they can control the ratio of non-anchor to anchor tasks to help students get to know each other and encourage them to work with each other outside the classroom. In addition, students who are struggling through the homework can conveniently get help from their classmates and the instructor. Second, Myers et al. observes, “As the weeks progressed, the number of anchor threads decreased. At the same time, students started discussing the link between everyday life experiences and physics more.” The fact that students are more comfortable with initiating discussions on their own later in the semester is very encouraging; the role of the instructor changes from an initiator to a facilitator throughout the semester. This shift means physics faculty who use this online discussion model for their courses only need to work the hardest during the first few weeks of the semester when students do not have strong connections with one another yet.

Many physics education researchers have been studying the use of online discussion forums in introductory physics courses. Duda et al. find that the online forum used for introductory physics students at Creighton University increases “student interactivity and the acquisition of new knowledge outside of class."[20] Although the results of this study show weak correlation between students' participation in online discussions and their performance in post-course survey, there is evidence that such participation helps increase student learning. In a different study, Kortemeyer studies the effectiveness of online forums as a tool to probe student's approach to physics homework problems and their learning attitudes. For this purpose, Kortemeyer compares online discussion forums to traditional surveys that students take throughout an academic year,

> The correlation between online discussion behavior and conceptual gains is stronger than the correlation between MPEX scores and conceptual gains, showing the value of online discussion behavior as a diagnostic tool.[21]

Though Kortemeyer cannot conclude that online discussion forums directly help students improve their understanding of physics and learning attitudes, the correlation between "online discussion behavior" and "conceptual gains" is still significant. The results from the studies about online discussion forums all suggest that they potentially improve students' learning experience and should be utilized more often in introductory physics.

Online discussion forums are not the only online platform that proves to be helpful in introductory physics courses. Another idea for utilizing the online platform that Regis already has comes from researchers at University of Edinburgh. A study by Hardy et al.

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[20] Duda et al., 2008

[21] Kortemeyer 2007

investigates a tool called PeerWise, which is an online tool that allows student to write multiple choice questions and explanations, share them with their peers, and, at the same time, answer, rate, comment on other students' questions.[22] The study includes 282 introductory physics students. Preliminary results show that there is a significant correlation between engagement with PeerWise and performance in the end-of-course exam. In addition, there is also evidence that students build strong connections with one another in the course as they participate in PeerWise activities. Since we have previously seen that stronger connections in the classroom lead to more collaborations outside the classroom, implementing PeerWise activities could potentially improve out-of-class collaboration.

The strategies I have shown here are just a few examples of community building activities that have been effective in physics classrooms at other universities. Implementing them at Regis will require further research and experimentation if we hope to experience the same level of success. In this chapter, I have discussed changes that instructors can make to the homework structure and the online tools. What I would love to focus on in the future is to study students' learning activities outside the classroom. As previously said, learning physics occurs both inside and outside the classroom. The success of some informal learning communities at other universities is a motivation for the physics community at Regis to invest in growing informal learning spaces. The COVID-19 pandemic and the limited amount of time I had for this study did not allow thorough

[22] Hardy et al., 2013

investigations into how informal learning communities develop. However, the insights from the faculty and the students who participated in this study are useful as we consider the next steps to build on what we learn from this study.

Where Do We Go from Here?

> "The important thing is not to stop questioning. Curiosity has its own reason for existence. One cannot help but be in awe when he contemplates the mysteries of eternity, of life, of the marvelous structure of reality. It is enough if one tries merely to comprehend a little of this mystery each day. Never lose a holy curiosity.''
>
> Albert Einstein[23]

Curiosity is, in my opinion, the greatest gift that each human possesses. In physics, curiosity is the fuel for exploration and the reason for stretching beyond one's comfort zone to learn and grow. In this thesis, I have shared stories and perspectives that are unique to the Regis University physics community. Through these perspectives, it is my hope that teaching and learning physics will not only be effective within the classrooms but also informally occur within the community itself. Perhaps, it is worth mentioning how studying physics at Regis has transformed my thinking and shaped me into who I am today to show that anyone, given enough support and effort, can learn and enjoy physics.

[23] Miller 1955

When I arrived at Regis and decided to major in physics, I did not immediately feel like I made the right decision. Throughout the introductory courses, I was curious enough about the subject to continue exploring it. When I became more active in the physics community during my sophomore year, my view of physics completely. I noticed that all of my fellow physics majors were brilliant thinkers; they all saw physics in unique ways. Some of them played musical instruments, and we often had interesting conversations about physics and music. Some of them wrote poems. Others were interested in teaching physics to young children. The physics community at Regis is small, but it has always allowed me to get to know what physics means to every student I encounter. For some reason, being a part of this community has shaped my physics identity.

For me, physics is not one single discipline. It is not the equations and principles in textbooks that give physics its meaning. For me, the people that learn, study, and do physics give it its meaning. During my time at Regis, I am grateful to find mentorship from the faculty and friendships from fellow physics students. My college journey would not be complete without this great community.

In this thesis, I have connected three different voices to form a picture of teaching and learning physics at Regis: physics faculty, students, and physics education research. Throughout the study, I have gained more insights into how physics is taught and the specific advantages and disadvantages of physics education in a small liberal arts environment such as Regis. I have also gained an appreciation for how hard it is to implement active learning strategies at Regis with the limited resources available to the Physics and Astronomy Department. For the same reason, developing a learning community outside the classroom is not an easy task as it requires continued experimentation and research to measure the effectiveness of different models that the Regis physics community implements.

The survey and interviews I have described took place during the COVID-19 pandemic, which allows to me observe learning and teaching behaviors in a very unique setting. However, my hope is to study the same behaviors under a typical in-person setting. The work I have done for this thesis provides various insights into physics education at Regis, but it is far from complete. With the limited time I had, I could only conduct a small number of interviews and gather responses from a small number of students. It is also my hope that a similar study will be conducted on a much larger scale based on the observations I have made in this study. There are many unanswered questions that this study has brought our attention to. As mentioned in the previous chapter, there has been much effort in developing active learning strategies within the classroom and building informal learning communities outside the classroom. This effort will undoubtedly continue in the future.

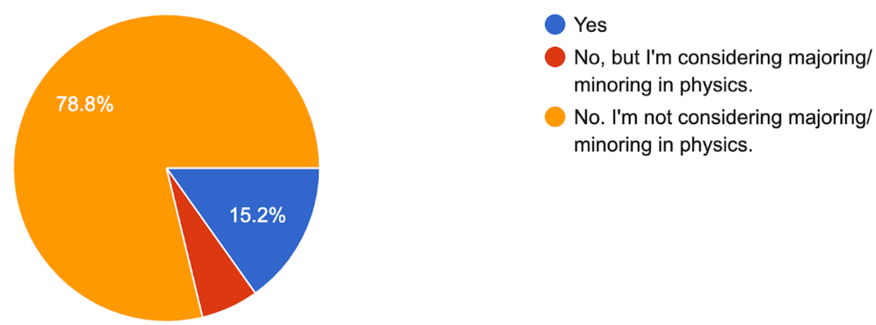
When I share with people that I do physics research, they will undoubtedly continue asking me, "What do you like about physics?" After four years at Regis and after this thesis, I have a much more complete answer than when I started. However, such an answer will never be perfectly complete, and we can always refine our understanding of physics education.

Appendix

Student Survey Responses

1. Are you a physics major/minor?

33 responses



2. What are some physics topics that you most enjoy discussing or learning about in your introductory physics courses? Why?

- Angular velocity and centripetal acceleration seem fun.
- Electricity and magnetism. It was easier to apply my physics 1 knowledge to electric and magnetic fields.
- forces and gravity, I find it interesting that one of the weakest forces is gravity compare to other forces like electromagnetic that's is 10^42 stronger than gravity.

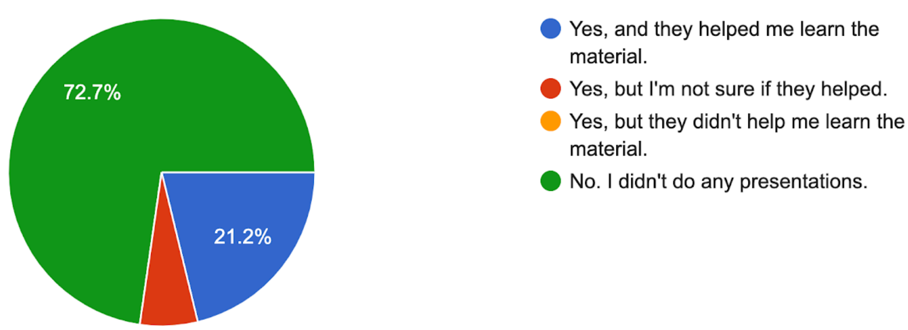
So far I have most enjoyed learned about forces. I have found this really interesting I think partially because I understand them the best and I can apply what I have learned to real life. I am excited to apply what I have learned to the human body.

- Honestly none of them really. I really liked physics in high school and thought I would enjoy it here, but I don't like it at all.
- circuit
- Collisions
- force of gravity, centripetal force
- Concepts of forces around an axis because I am a Health and Exercise Science Major so that easily relates to the forces our muscles create so our joints can move around an axis.
- I enjoyed learning about angular momentum because it blows my mind how a force on a rotating object applied in one direction can lead to movement in a completely different direction. I also really enjoyed learning and discussing special relativity. Special relativity is also very unintuitive and mind blowing.
- Force because I got to see that we actually use they in our everyday lives.
- Kinematics
- Centripetal acceleration and transfer of energy because it explains concepts in the real world that I find interesting.

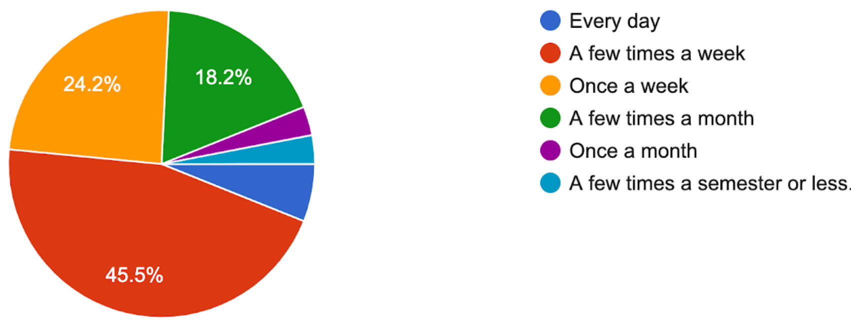
- I have liked Newtons laws the most because they made the most sense to me
- Friction and momentum
- Forces were enjoyable because when we were going through forces there was not any giant equations, but we could solve for the acceleration mass or force. While for being a more abstract concept then velocity or time made it more interesting.
- Forces because they are the most applicable to everyday life.
- I enjoyed learning about applied forces on varying objects in varying situations because I mainly liked doing the algebra portion of the solutions and providing numbers and factors to the forces on the object.
- force, easiest to learn/understand the concept
- I like learning about forces because it seems most applicable to my degree, which is HES
- kinetic motion. I understood it best.
- I like learning about all of them. I just find the class as a whole very interesting.
- I liked taking about sound waves and oscillators. I know they are different, but they really connected to what I learned in Chemistry and in Music. In a way physics branched these two areas of my study.
- Force because it’s been one of the easier things to understand.
- I like projectile motion and forces
- I enjoyed discussing energy and how it is applied in our world in various ways
- Things to do with athletics/sports- momentum, velocity, trajectory
- I liked Newtons laws and momentum, they seemed most applicable to everyday life

- I really enjoyed learning about forces and momentum because it applies to my major of HES and was interesting how forces affect the body
- I don't really have a favorite topic for physics. Overall, I find the subject as a whole interesting, but discussions can quickly become confusing. Overall, I enjoy learning about physics because it explains a lot about the world we live in and how things work.
- work, momentum, and gravity
- I like doing lab more than anything. more practical real-world application.
- I love learning about momentum and energy because those two have helped so much in my future courses.

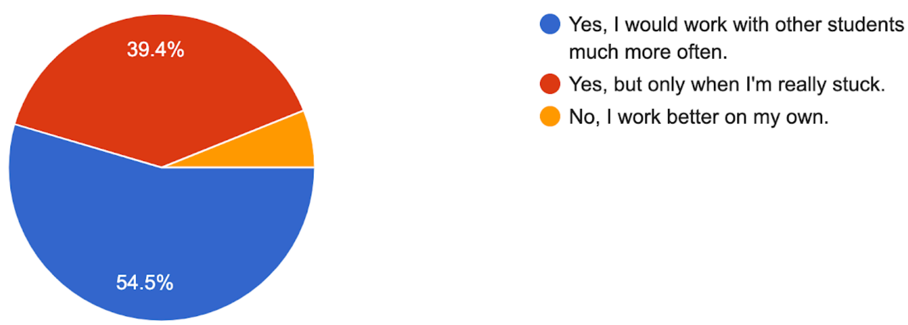
4. Did you do any presentations in your introductory physics courses? Did they help you learn?
33 responses



5. Do you collaborate with other students to work on homework or study for exams?
33 responses



6. Without the inconvenience of COVID-19, would you collaborate with other students more often?
33 responses



7. Explain the reason(s) for your response in question 5. (For example, are there obstacles preventing you from collaborating? What would make collaboration more appealing?)

- I just don't have as many friends or people that I know in this class to go out and work on homework with, but I would really like to.
- If the rooms were bigger and people were nice.

- It's awkward at first to gather with a group and study, everybody can be occupied or not interested. But when we spend more time together in class and get to know each other we are able to communicate and be comfortable with each other. To make this more appealing is to have a group chat or slack to chat. Another way is to gather a certain day and time once a week or month.
- I prefer asking questions to my friends who are also in physics and my boyfriend who a mechanical engineer is. It would be nice to be able to be in a classroom to ask questions and work on problems.
- I think I learn the best from my peers, I feel like I really haven't learned anything from the teachers really, so I have to teach myself or get help from my peers
- I collaborate when others are available
- Being a student athlete, we are limited to interacting with other students (due to COVID), it makes in person collaboration near impossible.
- Not everyone on zoom has their camera on or mic unmuted in breakout room when were supposed to be collaborating; don't necessarily know people in my class since were not in person, so hard to reach out to people
- It takes more effort to reach out to classmates and plan a time to get together versus if we were in class it would be easier to just ask in class or stay after to collaborate.
- I feel comfortable reaching out to my peers for collaboration. I reach out when I am making no progress and/or need someone to bounce ideas off of. I would say this usually happens once per week.
- I think it's harder to communicate through text, in person it is much better.

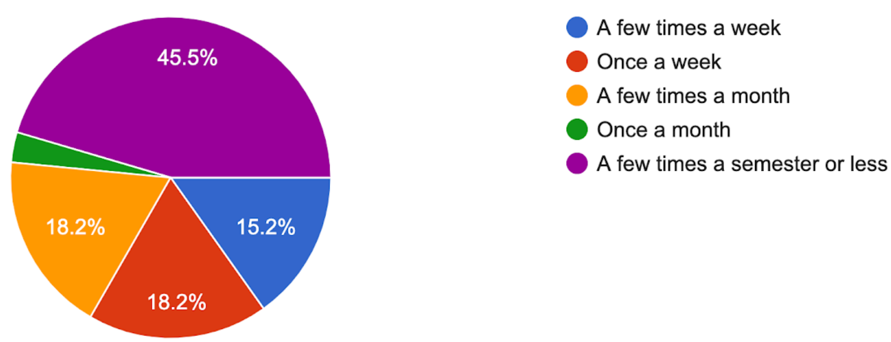
- Not being able to meet in class prevented collaboration.
- Covid has made collaboration hard because we never meet our classmates in real life. All I see about my classmates are their names, and sometimes faces during break out rooms. Therefore, its hard finding people to collaborate with.
- I like working with other students and find physics is always a lot easier to understand when you can just talk through things with people when you get stuck. I usually am really close to the answer and just need a little push to help understand what I know from the problem that I'm forgetting about.
- It would be easier to collaborate if we were in-person and got to know more people instead of just knowing people through zoom.
- I do not usually collaborate because I often times get confused by other students who are thinking incorrectly about questions.
- Since it is online class it is hard to click with people, so I mostly work by myself and with tutors
- What stopped me was the decrease of face-to-face aspect during the semester. I enjoy getting to know my classmates in a normal classroom setting and developing connections through these regular meetings. Through these relationships I feel more comfortable extending the idea to work together during the class.
- Working together over zoom, when you can’t see each other’s work on paper, and having to explain long equations is hard.

- It helps that a lot of my classmates are in the same major, so we all have each other's contact info and are comfortable reaching out to each other. I don't think I would collaborate as much if I didn't know my classmates as well.
- it’s hard to collaborate virtually sometimes/ through messaging on slack
- No, I just like to struggle through it because I feel like when I do figure it out then it'll really stick after I figure it out.
- At the time I was taking pretty intense classes. I think that didn't leave me enough time to study with other students a lot, but we did work on homework together.
- I do collaborate with other students for this class a few times a week because I don't do physics everyday but when I do, I reach out.
- There aren't really any obstacles, I like using other people because I feel like I learn better from my peers and professors rather than just one option alone.
- It is often difficult to collaborate with other students over zoom because it is not as personal. I do not feel as comfortable meeting with my classmates outside of class because I have never met them in person.
- I think having more people in my class that I am closer with would help more.
- I think we are less communicative as a class because we aren't seeing each other in person/getting to know each other
- Collaborating is really great, but COVID has made it difficult just because I don't get to meet or get to know as many people. If the breakout rooms changed more often during the semester so we could meet more people.

- I collaborated with my classmates on hw every week because I struggled with setting up the problems and having someone to bounce ideas off of was very helpful. It also helped to compare answers and check for mistakes.
- Due to Covid, I am not able to interact face to face with classmates, so we have to help each other through text and not everything is understood through written words. I need verbal explanations.
- I think it helps to talk it out when one gets stuck.
- I am a little socially awkward and sometimes it is easier to default to what I know and am comfortable with.

8. Do you take advantage of office hours and tutoring services?

33 responses



9. Explain the reason(s) for your response in question 8. (For example, are there obstacles preventing you from using these resources?)

- I would like to go more because I have a hard time understanding physics, but my schedule is pretty busy, so it is hard to find time.

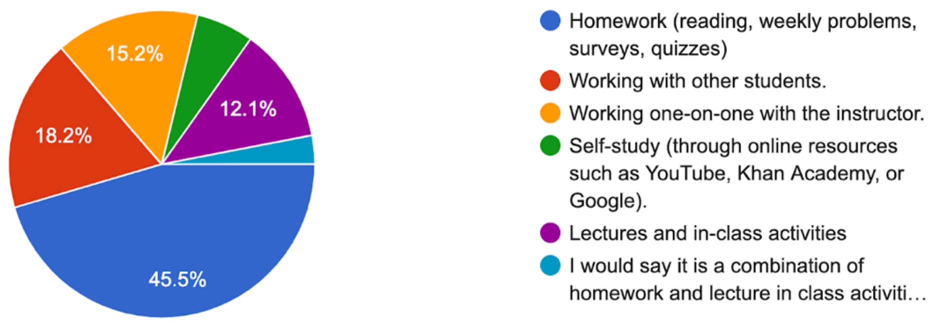
- Intimidating
- Not really you just have to make time which are pretty flexible in tutoring/office hours in my opinion
- I would use the tutoring services if I didn't have friends who were already helpful in teaching me physics. It is more convenient to ask them, but if I didn't have them I would go to tutoring.
- I need to go to tutoring
- none
- Lack of being on campus and in a classroom makes office hours less appealing.
- easy to use slack, professors are almost always on even at odd hours so easy to ask question when I have them; quick zoom call helpful easier than going too campus to see them in their office
- I don't really like to ask for professor's help unless I really need it.
- I will utilize office hours after I have collaborated with peers and still feel stuck or like I don't understand. I usually like to turn to my peers first then go to the professor. Although I don't use office hours often, I feel completely comfortable going to them when I do need help.
- I work so I don’t really have time, but I meet with my professor.
- No
- I think it’s hard only meeting on zoom, instead of having that resource right in front of you. It’s also hard knowing what to ask about when you're confused.

- No, I think I just start my homework too late and don't have time to meet with the professor or tutor before its due
- I do not like tutoring because some tutors make you feel stupid for not understanding the concepts. Also, it is hard to get tutoring times that work with a busy schedule.
- I use it when I need it or feel stuck on a question
- I started using them often and they are a great help.
- I am not very comfortable of being on camera with people that I am not close with. So, the idea of doing a zoom call with a tutor or person that I didn't know didn't appeal to me.
- would rather work with classmates, learning from someone who has years of experience can be hard and very confusing. they often explain topics more in depth and end up confusing me more
- I have a really busy schedule, so I only have a little extra time to use these resources. If I had more time I would probably go to tutoring more.
- I just use it when I need it
- Nope, I just only do it with the homework assignments.
- I had a hard time understanding the basic concepts, and tutors really helped explain these in a different way. I always went to the physics suite for tutoring when I needed help.
- I don't do tutoring because often the times don't work with my school schedule or work schedule.

- I play baseball, so it's hard to schedule an appointment in the hours given.
- I definitely have enjoyed using these resources and think they are very readily available
- Don't have a lot of available free time during the day because schedule is packed with classes and other extracurricular activities.
- tutoring hours don't work with my work schedule
- I feel really bad asking too many questions because I am so confused. I have heard the tutoring is not as helpful as going to office hours, but I don't want to have to meet with my professor every day to be able to complete the homework assignments. And when I have worked with my professor and collaborated with someone who got help from a tutor, they had a completely different answer from mine and typically it was wrong. So, it is hard utilizing all the resources because they are scarce and or unhelpful for an intro to physics class.
- Office hours and tutoring is very helpful because physics material can be challenging and having someone to explain concepts and guide you is very helpful.
- No, I just don't go.
- I would rather watch khan academy.
- Same as the other one there are no obstacles preventing me it is just easier for me to struggle alone than to ask for help.

10. In your opinion, what is the most important in learning physics?

33 responses



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