# Mathematical Content in Physics for Life Sciences Homework

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*This study presents a task-based content analysis of homework problems from a year-long, calculus-based physics sequence designed for life science students. Using a codebook created by adapting ideas from the Calculus Content Framework (CCF), we coded each homework task for the types of mathematical reasoning required, including derivatives, integrals, manipulating algebraic expressions, geometric reasoning, arithmetic calculation, and graph interpretation. Across the year, we found that manipulating algebraic expressions, arithmetic calculation, and geometric concepts appeared more frequently than calculus procedures such as derivatives or integrals. These findings align with prior work suggesting that algebraic skills and modeling are more central than calculus topics like derivatives or integrals in many physics tasks. As a preliminary study, this work invites feedback on how to build toward broader analyses, such as alignment with modeling-first calculus courses, with the long-term goal of better supporting students in navigating mathematics across disciplinary boundaries.*

*Keywords:* Calculus; Physics for Life Sciences; Task-Based Content Analysis

The overwhelming majority of students who take a calculus class in college are doing so as a prerequisite to other courses they are required to take to pursue their major. These chemistry, biological science, physics or engineering courses require the knowledge of calculus as a foundation of their discipline and courses. However, students' ability to transfer knowledge learned in their math courses to other subjects has long been a challenge.

We also see challenges in the mismatch of requirements for certain majors and career trajectories, such as toward medical school which generally encourage students to take a full year of physics, but only one semester of calculus (Ceder & Harrington, 2024; Columbia University – School of General Studies, n.d.; Rutgers University Health Professions Office, n.d.; University of Connecticut Pre-Medical and Pre-Dental Advising, n.d.). While these students do not usually continue taking calculus past the required courses, many of their other courses do require knowledge of calculus. To prepare students for medical school, universities might create versions of calculus or physics courses to specifically serve a population of students such as biology or pre-med majors which are tailored to that student population. These classes are especially important because research has shown that students' comfort with and interest in using mathematics to understand biology varies widely and is lower for women and first-generation students (Andrews & Airens, 2018). This project was motivated by a desire to understand the math present in a physics series specifically targeting biology or premed majors to assess how well prerequisite math courses prepare life science students for their subsequent coursework.

We hypothesize that misalignment between different courses might impede students' understanding and success (Ayene et al., 2010; Redish & Kuo, 2015). In particular, Bowers et al. (2023) emphasize the distinction between mathematical and scientific mastery, noting that students may successfully learn the necessary mathematics without achieving conceptual understanding in physics. Building on Redish and Kuo's (2015) work, we draw on their argument that success in physics depends not just on mastering mathematics, but on blending it meaningfully with physics reasoning. Their framework points to the need to consider how supporting students' use of math in a physics context may require reframing or extending what is typically taught in mathematics courses. While this report shares our analysis of homework problems we intend to use it as a foundation to examine student understanding more directly in future work.

Generally the strength of students' mathematical background appeared to correlate with their success in these classes (Ayene, 2010; Morán-Soto, et al. 2023; Quimson, 2021). To begin the work of determining how to better prepare students for subsequent courses such as physics we conducted a systematic content analysis of the math skills required for the completion of homework problems in the physics classroom. By classifying each task by the type of math skills it required, we aimed to show the specific mathematical emphases in these physics courses and how they relate to the math classes that preceded them.

We see this work as contributing to the understanding of the alignment or misalignment of math content in follow-on courses. We also see the need to consider how to support students to succeed in both their math courses and the courses they will go on to take later that make use of the math they learned. At the 27th RUME conference Robles and colleagues (2025) presented what they called the first study of math content in introductory physics using the calculus concept framework. We desire to build on their work with this examination of math content in an introductory physics course specifically targeting biological science majors. These desires led us to the research question for this preliminary proposal: What math content is present in a year long general physics class directed toward life sciences majors?

## Literature Review

While there have been research studies targeting the different ways math is taught in physics courses, not many have targeted the physics courses for life sciences. Much of the research has provided insights into how math in physics courses might differ from math in math courses. González-Martín (2021) and Hitier and González-Martín (2022) found that there is a difference between the way integrals and derivatives are taught and used in physics and math courses. Some authors even go as far as to say that the math taught in math courses is inherently different from the math in physics courses but can be bridged if math courses emphasized the ways to apply the tools math provides (Rabin, et al. 2025; Redish, 2006; Redish & Kuo, 2015).

There have also been studies that compare students' performance in STEM classes and how it correlates with their performance in math courses. In fact, three in particular concluded that it seems that students who have higher performance in math courses also perform better in their subsequent STEM courses ( Ayene, 2010; Morán-Soto, et al. 2023; Quimson, 2021). In a different study of how math background correlated with results in Physics 1 and 2 Burkholder and colleagues (2021) found that while math background was not a predictor of Physics 1 final exam scores, having completed vector calculus was a predictor of success in Physics 2. They found this appeared to be primarily due to better reasoning about vectors and geometry, not specifically vector calculus skills.

Projects that analyze the math content in STEM courses find few uses of the math learned in prerequisite calculus courses (Faulkner, et al. 2020, Robles, et al. 2025). Ayene (2010) puts this in a greater context by comparing the math content in physics courses throughout a physics program and whether they align with content from each prerequisite math course and determines that there is in fact misalignment in math content within this sequence of courses. There appear to be few studies that look at the broad use of math in introductory physics courses specifically. Our project continues the research seen in these papers such as that completed by Robles and colleagues (2025) through our analysis of the mathematical content in a physics sequence designed for life sciences.

## Analytic Framework

To analyze the mathematical content in subsequent physics courses we adopted a task-based content-analysis approach. We wanted to evaluate the math content to see how well calculus courses are preparing life science students for these calculus-based physics courses. We treated each subpart of a homework problem as a task that a student had to accomplish and used instructor solutions to determine which techniques were used in each task.

To determine the math content present in each problem we considered the definition of calculus from the Calculus Content Framework (CCF) (Sofronas et a., 2011). The framework breaks out a number of concepts and skills that calculus experts deemed part of first year calculus. Perhaps unsurprisingly the first few skills that showed up in their study were derivative computations, techniques of integration and limit calculations. After this is a longer list of items identified by 1-4 participants, these included: sequences/series, manipulating algebraic expressions, area/volume, parametric equations, polar coordinates, trigonometric manipulations, facility with logs and exponentials, epsilon delta proofs, listening/reading comprehension and facility with definitions and notations. After consideration of this list and initial review of the problems we were coding we decided to keep the first couple of categories but to bucket together, adjust or leave out several of the categories that came up among fewer of their participants and that did not appear relevant to the calculus problems. We also wanted to include a code specifically for arithmetic calculation which we saw show up a number of times in problems. In the next paragraph we define each of the codes we used to understand the math present in the physics homework.

For the concepts of *derivatives* and *integrals* we used Sofronas' and colleagues' (2011) discussion to develop short descriptions. We also included a code for *manipulating algebraic expressions* which encompassed solving for unknowns, rearranging equations, and symbolic manipulation (Puig & Rojano, 2004) and included the expression of physical relationships. This code also included two sub codes, *summation notation* and *delta notation*, which appeared frequently in the problems although generally used differently than is typical in calculus classrooms. The final bucket we considered was *geometry*, which included area/volume, spatial reasoning, diagrams, coordinate systems, and shape-based interpretation (Jablonski & Ludwig, 2023). This bucket also included *vectors* and *trigonometry* as specific child codes.

Finally, we added an emergent code, *graph interpretation*, for problems requiring students to extract quantitative relationships from visual representations, a skill recognized as distinct in both mathematics and science education research (Roth & Bowen, 2001). This skill also came up in the CCF in connection with derivatives, but many of the problems that appeared to involve graphical interpretation in this set did not necessarily involve derivatives.

## Methods

To analyze the mathematics present in the physics sequence, we obtained the complete written homework problem sets and instructor-provided solutions for each semester. These solutions offered insight into the instructor's expectations and represented the problem-solving techniques students were likely expected to use. We conducted a task-based content analysis of the homework sets to identify the mathematical skills required to complete each problem. We also analyzed online homework sets that did not include instructor solutions. These questions were multiple choice or short numerical responses. While these tasks still provided some information, the absence of solutions and limited response options led us to question exactly what mathematical skills were required for the problems and to what degree they were required.

Each homework problem and its subparts were categorized as either requiring mathematics or not. In cases where mathematical work appeared in the instructor's solution but was not necessary to solve the problem, we applied an additional tag, “math in soln.” To code the math content in each problem we devised a codebook in line with the calculus concept framework, but adjusted as described in the theoretical framework above.

The codebook was implemented in Microsoft Excel, with problem numbers, brief descriptions, and math tags documented to ensure consistency in analysis. Each problem was independently coded by both authors, and disagreements were discussed and resolved through consensus. Initial agreement rates were high, and once coding was complete, we conducted an informal member check by sharing our coding with the physics instructor, who confirmed that our characterizations aligned with the intentions for the problems.

## Findings

In classifying the homework problems, we found that the majority of problems required math skills with 63% of problems across the sequence coded as involving math content in some way (n=240 of 379). Similarly, in the online homework 74% of the problems were coded involving math content (n=221 of 297). We found that the majority of math content required of students as represented by the homework problems involved manipulating algebraic expressions but only a minority included calculus specific skills such as calculating derivatives or integrating.

The skill most commonly appearing in the written problems was manipulating algebraic expressions with it showing up in 77% of the problems that involved math skills (n=185). The second most commonly appearing code was arithmetic calculation which appeared in 50% of the math problems (n=121). Geometry was the third most common code occurring in 43% of problems (n=103) with its subcodes of vectors (n=54) and trigonometry (n=54) each appearing in 22% of problems. Derivatives came up in 8% of problems (n=19) and integrals in 4% of problems (n=9). The most common skill in the online homework problems was arithmetic calculation showing up in 76% of problems (n=167) and manipulating algebraic expressions was the second most common code showing up in 25% of the problems (n=62). Considering the format and intent of the online problems, these skills being most common makes sense; these questions are intended to check basic, often conceptual, physics skills newly introduced in the class sessions. Derivatives were only coded in 2% of the online problems (n=4).

Beyond the frequency of the problems we also noted in coding that summation notation (n=11) and delta notation (n=32) were used in ways not generally seen in calculus curriculum. In the physics curriculum summation notation was often used as a stand-in for writing “sum” when a problem asked for summing up a number of different forces for example. This use is distinct from how students usually see summation notation in calculus courses in the context of series. Although we only did a formal review for the homework assignments, we performed an informal review for the in-class session activity handouts and found more calculus there. The calculus involved derivatives, chain rule, integration, differential equations, and calculus in 3 dimensions. No analysis was done of section activities, exam study materials, or supplementary resources.

## Discussion

### Different Emphases

Our analysis of these homework problems demonstrates that the math skills students use most frequently in an introductory physics series like this one differ from what calculus experts deem the emphasis of their classes. This difference is not necessarily surprising as the focus of a calculus class is the understanding and implementation of the mathematics content itself. Math teachers need to support math understanding for students with broad aspirations while in physics the math provides tools for understanding the content of that discipline. While not surprising, we think this finding is important because when a course is a prerequisite then students would expect that completing that course means they are prepared for subsequent courses that require it.

This work reveals however that for success with the mathematics present in a course like this a solid foundation in algebraic and geometric knowledge and skills may be more important than skills related to manipulating derivatives and integrals. Many students likely enter their calculus courses already with strong algebra and geometry skills. However, for the subset of students that do not have a strong background in algebraic manipulation there is no guarantee that their calculus course will address these skills. As the CCF shows, many calculus educators emphasize new content like manipulating derivatives and integrals, but not the previously mentioned skills.

This disconnect between the emphasis of calculus topics and possibility that students get through without addressing gaps in their algebraic manipulation skills is especially salient in courses targeting life sciences majors. Students in these majors, especially those selecting these targeted courses, may have a more negative relationship to mathematics than other STEM majors (Wachsmuth et al., 2017). With this population that may be interested in being veterinarians or doctors, we need to consider the best options to serve them mathematically. This work shows that within the context of a physics class specifically designed for this population, the most commonly used skills aligned more to the modeling aspect of calculus rather than advanced differentiation and integration techniques.

**Directions for Future Research**

Our findings align with prior research and show that a lot of mathematics work is required of students in physics classes and confirm why prior studies have shown alignment between students' math skills and success in physics coursework, even if content does not necessarily align (Ayene, 2010; Morán-Soto, et al. 2023; Quimson, 2021). We consider this work preliminary because our true interest is in how to better support students' transition and transfer from calculus to physics, a well known and complex challenge.

This study provided insight into the skills that are most commonly required for students to succeed in a physics course targeting life sciences majors. These results align with Robles and colleagues' prior study that showed that in introductory physics the most prevalent skill required is algebraic manipulation with trigonometry, vectors, and graphs coming up more frequently than integrals or derivatives even in a calculus based physics course.

Others have recognized this disconnect and created alternative forms of calculus such as modeling-first approaches to calculus for life sciences students which have shown some success (Garfinkel et al., 2022; O'Leary et al., 2021). In future work we would like to analyze problem sets from these courses and more traditional calculus courses to see how they compare. We also want to analyze more physics for life sciences classes to see trends in mathematical content. Furthermore, we would like to look at student outcomes or consider conducting cognitive interviews with students to look at what they know and how it translates.

## Questions

As a preliminary report, audience engagement is much appreciated, and we offer questions. Would further content analysis likely bring new insight into knowledge requirements, or should additional methods, like interviews, be used? What suggestions would you have for us to deepen this study further and make it more relevant to how we can better support students?

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