Does Physics Really Need to be a Preqrequisite to Statics?

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Abstract

Depending on the university, first-year Introductory Physics, where students are usually introduced to mechanics at the collegiate level, may or may not be a prerequisite for students taking Statics. At first glance, requiring the successful completion of a first-year physics course for students to take Statics seems logical. After all, it is in Physics where students are introduced to the concept of free-body diagrams (FBDs) and Newton's 2nd law, and this knowledge should, in theory, help students be successful in Statics, a class that uses these ideas extensively. While the intent of the Physics requirement is clear, our anecdotal observations in the classroom did not support the assertion that students who had completed an Introductory Physics course necessarily performed better in Statics than students who took Physics and Statics concurrently. In this paper, we qualitatively and quantitatively investigate the advantages and disadvantages of having an Introductory Physics course serve as a prerequisite for or a corequisite to Statics. As a result of this work, we have found that while students who take Introductory Physics concurrently with Statics initially perform demonstrably worse compared to their counterparts who take Physics as a prerequisite to Statics, there is significant improvement in the scores of the former group as the term progresses. This quantitative comparison, combined with qualitative observations from students which strongly favor requiring Physics as a prerequisite, seems to support the surprising conclusion that most students would benefit from taking Physics as a prerequisite to Statics.

Introduction

As the first engineering course that students typically encounter, Statics is an important gateway to the rest of the curriculum as evidenced by the fact that it serves as a prerequisite for higher-level courses like Dynamics and Mechanics of Materials almost universally. However, there is far less consistency between universities with regards to the prerequisite and corequisite courses for Statics itself. Table 1 provides a summary of the prerequisites and corequisites to Statics (or its equivalent) at select mechanical engineering programs around the country.

As can be seen from Table 1, there are significant differences in the math and physics requirements for students entering Statics depending on the university. Since one of the primary goals of the class is to teach the students how to draw correct free-body diagrams regardless of the university, this inconsistency seems to suggest that not all these pre/co-requisites may be completely necessary for students to succeed in Statics.

In this paper, we will focus on Physics I, which generally covers the basics of mechanics amongst other topics, as a pre/co-requisite for Statics. A brief literature survey on this topic provided contradictory results. Hu et al. [1] and Anderson et al. [2] have shown a relatively strong correlation between the prerequisite Physics I grade and the Statics grade of students at their respective institutions. In addition, Wingate et al. [3] identified Physics as the most important course in the mechanics sequence that can foretell continued problems throughout the mechanical engineering curriculum. However, a statistical study by Zhang et al. [4] showed a student's performance in Physics lecture courses had no statistically significant effect on retention in engineering. Moreover, Myszka [5] observed that for engineering technology students, there was no correlation between completing a physics course and performance in engineering mechanics. Furthermore, Cornwell and Danesh-Yazdi [6] reported that some poor practices in drawing free-body diagrams (FBDs) such as concentrating all the forces acting on the system at a single point are learned in introductory Physics and might be difficult to correct later on in Statics.

Table 1. Pre/co-requisites for the Statics course (or its equivalent) at select universities

Mechanical engineering program	Course name	Pre (P)/co (C)-requisites
CalPoly San Luis Obispo	Engineering Statics	Physics I (P) and Calculus IV (C)
Caltech	Mechanics	Sophomore standing (P)
MIT	Mechanics and Materials I	Physics I (P) and Linear Algebra or Differential Equations (C)
Ohio State University	Statics and Introduction to Mechanics of Materials	Physics I (P) and Calculus II (P)
Penn State University	Statics	Calculus II (P/C)
Rose-Hulman Institute of Technology	Statics and Mechanics of Materials I	Calculus I (P)
Stanford University	Intro to Solid Mechanics	Physics I (P)
UC Berkley	Introduction to Solid Mechanics	Physics I (P), Calculus III (P), Linear Algebra (C)

The purpose of this paper is to examine the benefits and drawbacks that may accompany requiring a first-year Physics course as a pre/co-requisite for Statics. We provide some qualitative observations from our own experiences teaching Statics as well as the perspective some students expressed in their student evaluations. We also compare midterm exam data for similar topics for students who took Physics as a prerequisite and those who took it as a corequisite.

Physics I as a Corequisite to Statics: The Good and the Bad

The course at our institute

At Rose-Hulman Institute of Technology, Statics is taught in a two-quarter sequence as a combined “Statics and Mechanics of Materials” course. The first quarter of this sequence is in effect a typical Statics class with basic topics in Mechanics of Materials such as normal and shear stress sprinkled in. The second quarter of the sequence is similar to a standard Mechanics of Materials course. Throughout this paper, any mention of Statics refers to the first of these two courses: “Statics and Mechanics of Materials I”.

At Rose-Hulman, Physics I is neither a prerequisite nor a corequisite for Statics, but freshmen typically take it in their first quarter. Some students who are admitted to the Institute with Calculus I credit may choose to take Statics and Physics I simultaneously in the Fall quarter, since Calculus I is the only prerequisite for Statics. Most students, however, complete Physics I in their first quarter and take Statics in the Winter quarter. The lack of an introductory Physics requirement for Statics at Rose-Hulman provides a unique opportunity to study student perception and performance in Statics with respect to when the students take Physics I and to see whether establishing Physics I as a prerequisite to Statics is necessary.

Qualitative instructor observations

As Statics instructors, we recognize the importance of *some* pre/co-requisite courses for Statics. From our experience, students *must*, at a minimum, have a basic understanding of vectors, geometry and trigonometry before taking Statics. Depending on course coverage, calculus may not be completely necessary if, for example, the instructor is not interested in problems involving finding maxima or minima of functions or deriving centroids using integration. From our collective experience, however, the necessity of Physics I to Statics as a pre/co-requisite is not as clear. We will first consider the scenario where Physics I and Statics are taken concurrently.

One potential issue with treating Physics I as a corequisite with Statics is that Statics instructors may teach the course assuming students have prior knowledge of certain fundamental physics concepts. By contrast, instructors for an introductory Physics course typically do not make assumptions about prior knowledge and therefore try to teach concepts at a more basic level. For example, it is less likely in an introductory Physics course for an instructor to assume students already know what a gravitational force is and how it acts on a body, whereas in Statics it is often assumed to be known. It may be true, then, that students who are taking Physics as a corequisite with Statics may struggle in Statics with concepts that are not explained in Physics until a later time. Table 2 below provides information on the planned topics for a ten-week course in Statics and Physics I to provide a basis for comparison.

Table 2. Comparison of topics in Statics and Introductory Physics

	Statics	Physics I
Week 1	Vector math	Vector math
Week 2	Particle equilibrium	1D kinematics
Week 3	Stress-strain relationships	2D kinematics
Week 4	Statically indeterminate loading	Newton's laws
Week 5	Moments, centroids, and distributed loads	Work
Week 6	2D equilibrium (rigid and deformable bodies)	Energy
Week 7	Frames and Machines	Electromagnetic force
Week 8	Friction and 3D equilibrium	Gravitation
Week 9	3D equilibrium/statically indeterminate systems	Momentum
Week 10	Trusses	Review

Two major topics seem to be aligned between the two courses – vector math and particle equilibrium using Newton's Laws. Although students learn vector math in both classes at roughly the same time, some Physics instructors choose to wait to teach portions of vector math until the information will need to be used. For example, cross products may instead be taught closer to the end of the term since the next introductory Physics course begins with a discussion of torque. Since students in Statics are expected to use cross products in the first week– and since it may be true that some Statics instructors assume students have gained this knowledge in high school or through other courses – it is understandable that Statics students who have not yet taken Physics might struggle towards the beginning of the course.

The issue becomes more pronounced when particle equilibrium is introduced. Students taking Physics as a corequisite with Statics will begin working particle equilibrium problems in Statics two weeks before they see the corresponding material in Physics. Not long after this, they have moved on to handling rigid and deformable bodies, where it is no longer assumed that all forces act through a single point. In this case, there may be a benefit to taking Statics as a corequisite. Rather than learning to draw a particular type of diagram specifically for particle equilibrium (as is taught in Physics) and then un-learning it when moving on to rigid and deformable bodies, Statics instructors can be more proactive about ensuring that students understand when it is appropriate to make certain assumptions (e.g. all forces acting through a single point).

Qualitative student observations

The following qualitative observations are drawn from the student evaluations of one instructor's Statics course for which the students were taking Physics as a corequisite with Statics. Students were prompted with the following statement: “Describe one or more ways this course can be improved.”

> *Physics I needs to be a prerequisite for this course. I cannot believe that it isn’t already. I believe the root of many of my struggles towards the beginning of this course was due to the fact that I had not yet taken Physics I. Half of the confusing information that I received in this class I learned a couple weeks later in my Physics class. I believe students who have already taken and passed Physics I will have much more success in this course than those that have not had the chance to.*
>
> *Ensure that students who have no background in physics understand topics which may require prior knowledge.*
>
> *The course starts at a very basic level, and so I feel like we wasted 2-3 weeks doing very elementary things. I feel like Physics 1 and Calculus 1 should be made pre-requisites, and so concepts such as vectors should be assumed knowledge so we can cover more concepts in class.*

These comments seem to represent the classroom experience of two different categories of students – one group (with a perceived weaker background in physics) that appears to feel overwhelmed by the pace and content early in the course and another with a strong understanding of underlying topics who felt the pace was too slow. Both groups of students, however, favor requiring Physics as a prerequisite for Statics. It would allow some of the introductory content – such as vector math and particle equilibrium – to be removed from Statics, making time for more depth to cover some less familiar and more challenging Mechanics of Materials concepts such as stress-strain relationships and statically indeterminate systems. Including Physics as a prerequisite would also put students on a more equal footing so that the pace of the class is perceived to be more comfortable for all students.

Physics I as a Prerequisite to Statics: The Good and the Bad

Qualitative instructor observations

The majority of the students who enter the Mechanical Engineering program at Rose-Hulman take Physics I along with Calculus I in the Fall quarter of their freshman year and move on to Statics in the Winter quarter. Perhaps the most persistent problem that is encountered in Statics with students who have passed Physics I is what they are taught about drawing FBDs. They often enter Statics by drawing systems as a point or they put all the forces at the center of gravity. Due to the breadth of material that needs to be covered in Physics I as outlined in Table 2, students are introduced only to particle equilibrium and from our discussions with Physics faculty members, they often teach their students to draw all of the forces acting on their system as passing through a single point. While this will yield a correct solution for particles, the fact that friction or the normal force is drawn going through the center of gravity of the system can and often does lead to poor habits that may be difficult to correct in Statics. It is also worth noting that Physics instructors do correct these practices, but they do so at the beginning of the Physics 2 course.

The positive aspects of having Physics I as a prerequisite to Statics are fairly clear. Freshmen have the opportunity to become better acclimated to the college environment in their first quarter by going through a more general Physics I course as opposed to a more rigorous course in Statics. Physics I also provides students with an opportunity to practice vector math and identifying systems and drawing FBDs at a more elementary level before encountering these topics in Statics. This is especially helpful in a 10-week quarter because students do not have as much "soak time" to absorb the material presented to them as compared to a 15-week semester.

Qualitative student observations

For a more complete picture of how students believe their experiences in Physics have prepared them for Statics, students in one instructor's Statics course who had taken Physics I as a prerequisite were asked to answer the following questions:

1. Have you successfully completed PH111 with a passing grade before taking this class?
   (Yes/No)
2. If you answered "yes" to Q1, please answer the following: If you had *not* taken PH111 before taking this class, how would you feel you would be performing compared to how you are doing in the class now?
   (Better/Same/Worse)

Of the 20 students who has passed Physics 1 prior to taking Statics, 16 felt that they would have performed worse in Statics without having taken Physics I, and the remaining 4 felt they would have performed the same. Although related comments were not collected allowing students to explain their choices, it is likely that their reasoning for valuing Physics as a prerequisite is similar to those already discussed – learning related material in Physics allows the students to practice related skills in a simpler context before learning Statics. It is unsurprising that no students highlighted their Physics experience as harmful to their Statics knowledge. It is unlikely that most students would pick up on the same potential issues that instructors may be able to identify like poor practices in drawing FBDs.

Quantitative comparison of student performance in Statics

As shown in Table 1, there are very few mechanical engineering programs that do not require Physics I as a prerequisite to Statics in the United States, which makes testing the necessity of a Physics I pre/co-requisite difficult. Thankfully for our purposes, the lack of a Physics I pre/co-requisite coupled with a statistically significant number of students who take Physics I either as a prerequisite or corequisite to Statics make this analysis possible at Rose-Hulman.

In order to quantify the differences in performance for the two group of students, we decided to look at their midterm exam scores in the Fall and Winter quarters of Statics taught by one of the co-authors. The reasoning for this was to keep the grading criteria as similar as possible between the two classes. The mean, median and standard deviation of student performance on similar problems in the Fall and Winter quarters of particular academic years is presented in Table 3. These results were deemed to be IRB-exempt at our institution. It is noteworthy to mention that Exams 1, 2 and 3 were administered at the end of Weeks 3, 6 and 9, respectively, and covered the following topics:

- <u>Exam 1</u>: Vector math, particle equilibrium and stress-strain relationships.
- <u>Exam 2</u>: Factor of safety, statically indeterminate systems, rigid-body equilibrium, moment definition and centroids.
- <u>Exam 3</u>: Frames and machines, friction, 3D equilibrium and statically indeterminate systems.

The results in Table 3 reveal several interesting aspects about the two groups of students (henceforth referred to as the "prerequisite" vs. "corequisite" group):

- The overall performance of the students in the "prerequisite" group was statistically better on Exam 1 than their counterparts with up to 98% confidence. The difference between the two sets of students is essentially due to the two problems that involve drawing FBDs (particle equilibrium and determining stress in a member). This result is even more surprising since, historically, the Fall quarter class has been comprised of students who are usually academically stronger than their Winter quarter counterparts (as evidenced by their ability to test out of Calculus I). In terms of exam difficulty, the particle equilibrium problem in the Fall quarter required more nuance to solve (Figure 1a) compared to the problem in the Winter quarter (Figure 1b), but the stress in member problem in the Fall and Winter quarters was at about the same level of difficulty (Figure 2). Taking all these facts together, one can conclude that the "corequisite" was simply not as prepared for Exam 1 as their counterparts. One possible reason for this is that the "corequisite" first encountered particle equilibrium in Week 4 of their Physics I class, which occurred after Exam 1 had already been administered. They simply did not have as much reinforcement and repetition on this material as their "prerequisite" counterparts. They are also likely less prepared for the rigors of a college exam. For most of the "corequisite" group, Exam 1 was their first or second exam in their college careers and that might also have been a factor in their poor performance.

- The overall performance of the students in the "prerequisite" and "corequisite" groups for Exam 2 was statistically similar. While the "prerequisite" students effectively maintained an average similar to Exam 1, there was a significant jump in the average for the "corequisite" group. The exams were of a similar level of difficulty. The jump in scores could possibly be attributed to factors such as having had the reinforcement on particle equilibrium from Physics I and adapting better to a college environment.

Table 3. Comparison of midterm exam performance in two Statics courses taught by the same instructor

Mean [Median] (Standard deviation)		**Fall quarter (Physics I as a corequisite) *N* = 24**	**Winter quarter (Physics I as a prerequisite) *N* = 27**	***p* value of scores (statistical significance)**
Exam 1	**3D vectors**	80.0% [90%] (20.9%)	78.4% [75%] (15.2%)	0.75
	Particle equilibrium	67.2% [73.3%] (23.6%)	89.0% [92%] (10.5%)	0.000032
	Stress in member	59.7% [60%] (20.2%)	74.0% [76.7%] (16.2%)	0.0061
	Total	67.3% [71%] (17.2%)	76.5% [78%] (11.0%)	0.020
Exam 2	**Factor of Safety/Rigid-Body Equilibrium/3D Moment/Couples**	71.5% [68%] (14.5%)	76.8% [75%] (13.7%)	0.18
	Statically Indeterminate Systems	76.9% [80%] (17.0%)	69.1% [70%] (20.7%)	0.14
	Total	79.0% [81%] (10.7%)	78.7% [80%] (12.5%)	0.94
Exam 3	**Total**	85.3% [87%] (9.1%)	80.0% [81%] (10.4%)	0.060
Final Exam	**Total**	83.3% [84%] (10.0%)	83.2% [81.5%] (11.3%)	0.97

- The improvement that was evident in the “corequisite” group from Exam 1 to Exam 2 continued to Exam 3, while the “prerequisite” group maintained a relatively consistent performance throughout the quarter. Again, the level of difficulty of the two Exam 3’s was about the same. It is fascinating that in the span of 3 midterm exams, the performance of “corequisite” group improved by nearly 20 points, to the point that their overall mean score was statistically better than the “prerequisite” group (with up to 94% confidence), a complete reversal of the results of Exam 1. It is clear in this case that the “corequisite” group of students started to develop a better understanding of the course material between the first and second exams and continued to improve until the end of the quarter.

- On the cumulative Final Exam, which was identical in the two quarters, the two groups performed in a virtually identical manner. This suggests that by the end of the quarter the effect of having had Physics I as a prerequisite or corequisite to Statics is identical. This is somewhat expected since by that point, both sets of students have seen Physics I in its entirety.
- In speaking with two other colleagues who have taught Statics in both the Fall and Winter quarters, a similar trend with respect to the "corequisite" group (starting off poorly, showing significant improvement on Exam 2 and continuing to improve for Exam 3) has been observed in their classes as well, which tells us that the observations from this particular set of data is likely not an outlier.

Conclusions

In this paper, we have presented some qualitative and quantitative benefits and drawbacks of treating Physics I as a corequisite or prerequisite of Statics from an instructor and student perspective. The quantitative and qualitative perspectives provided in this paper generally seem to indicate that most mechanical engineering students would benefit from taking Physics I as a prerequisite to Statics. Taking Physics I as a prerequisite allows students to become more comfortable with overlapping topics – such as vector math and particle equilibrium – prior to taking Statics. This may to lead to improved performance during the first half of Statics as evidenced by the comparatively better performance on early midterm exams in students who have already completed Physics I. However, we do recognize that other factors, such as requiring a transition period to adjust to the college setting, may also be significant in the gap in scores we observed for early midterm exams. Furthermore, Statics instructors may also benefit from a required Physics I prerequisite. This requirement would provide a very clear picture of what students should be expected to know when they enter Statics and would allow Statics instructors to shape their course content accordingly. For example, Statics instructors may choose to eliminate vector math from the course altogether and instead use the time to focus on newer and more challenging topics. This change would also lead to a pace that is perceived as more comfortable by the whole class in general, rather than leaving a portion of the class feeling behind and another portion feeling bored. The primary concern with requiring Physics I as a prerequisite is that the insistence on placing every force at a single point in Physics can lead to poor FBD habits in Statics, and these habits may be difficult to correct. To address this issue, Statics instructors may choose to place more emphasis on the correct approach to drawing FBDs for rigid and deformable bodies in the first few weeks of the course. They may also pair with Physics faculty to develop an approach to teaching FBDs that will work well for both courses.

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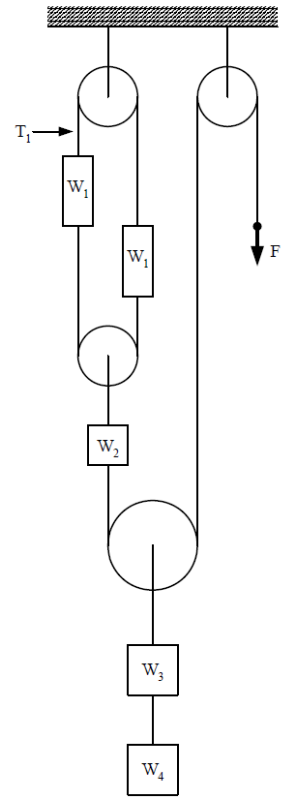
Figures

A series of four ideal massless, frictionless, pulley and five blocks are arranged and interconnected with rope in the vertical plane as shown. Each block is identified with its respective weight W_i, i = 1,2,3,4. Determine the (a) force F required for equilibrium as a function of the known quantities, (b) tension T_1 in the rope section shown as a function of the known quantities.

Knowns: W_1, W_2, W_3, W_4



Ropes *AB* and *BC* are attached to block *B* which rests upon a frictionless horizontal surface. Ropes *BC* and *CD* support the 100 lb. weight at *C*. Find the equation necessary to determine the tensions T_{AB}, T_{BC}, and T_{CD}.

Set up the equations but do not solve them. *Clearly* number your equations and list your unknowns.

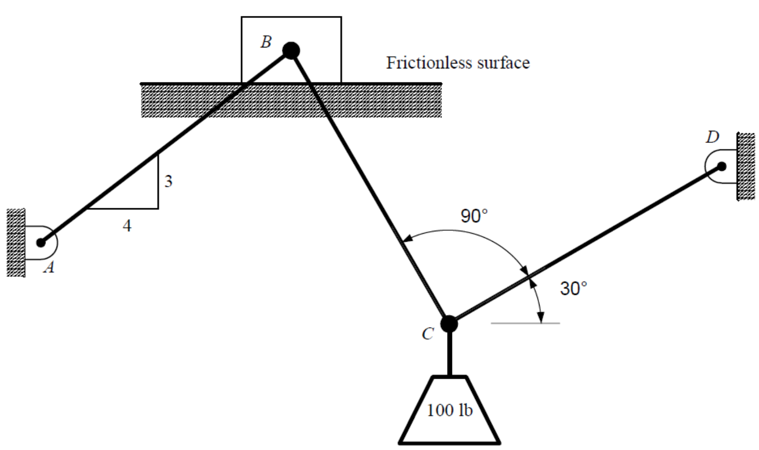


Figure 1. Exam 1 particle equilibrium problem: (a) Fall quarter, (b) Winter quarter

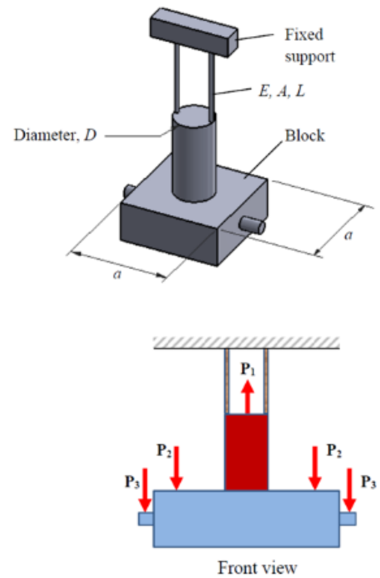
The round cylinder of diameter D is suspended by two cables (lengths L, areas A, Young's modulus E) and supports a block as shown. The known forces **P1**, **P2**, **P3** are shown in the front view. Determine the:

(a) normal stress in the cylinder (13 pts)

(b) cable deflection (13 pts)

(c) minimum normal stress in the block. (4 pts)

Knowns: P_1, P_2, P_3, D, E, A, L



A 4-ft section of aluminum pipe of cross-sectional area 1.75 in2 rests on a fixed support at A. The figure shows a cross-sectional view. The 5/8-in.-diameter steel rod BC hangs from a rigid bar that rests on the top of the pipe at B. Forces are applied at B and C as shown. The modulus of elasticity is 29×10^6 psi for steel, and 10.4×10^6 psi for aluminum. Determine (a) the normal stress in the pipe, (b) the normal stress in rod BC, (c) the final length of the pipe.

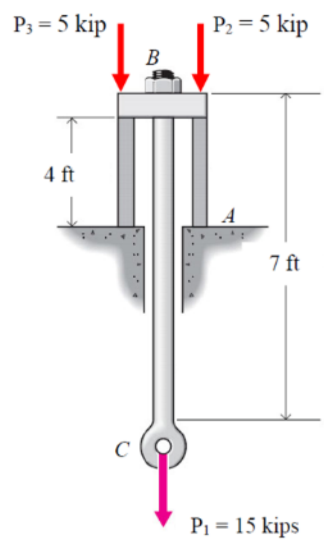


Figure 2. Exam 1 stress in member problem: (a) Fall quarter, (b) Winter quarter