Evaluating a Physics Problem Tutorial Format in Upper-Level Undergraduate Electromagnetism Courses

Dorian Baldwin-Bott

August 12, 2024

Advisor: Dr. John Colton

Physics 492R Capstone Project Report

Abstract

Despite the ubiquity of problem-solving resources available to undergraduate students in introductory physics courses, many undergraduates in upper-level physics courses continue to struggle to develop or apply an effective problem-solving framework to new material. While there are several resources available to upper-level students, these resources tend to be focused on either specific aspects of problem solving (e.g. conceptual understanding or mathematical reasoning) or specific topics within an upper-division course. These issues have been addressed by creating a prototypical problem tutorial format that encompasses all aspects of problem-solving and is flexible enough to be used for different topics. This report will evaluate this tutorial format by reviewing student feedback and grade performance now that tutorials of this type have been implemented in three separate upper-level electromagnetism classes (Fall 2022, Fall 2023, and Spring 2024). From this analysis I have determined that this tutorial format shows a modest but consistent pattern of success that is worth further implementing and testing.

Acknowledgements

I would like to express my immense gratitude to those who worked alongside me with this project, in particular my advisor, Professor John Colton of Brigham Young University, who has provided me with crucial encouragement, counsel, and support. I also send my thanks to Grant Miller and James Hecht, fellow students who worked alongside me at various points of this project, Dr. Andrew Mason of Central Arkansas for his guidance and expertise in the field of physics education research, and Dr. David Neilsen of Brigham Young University for his willingness to assist in this research.

Background

There are few things as satisfying as the moment a student *finally* understands the problem you have been reviewing with them for the past hour. You can tell from their face the moment they find clarity, watch the relief wash over them as they realize that they will be able to finish the assignment in front of them, and hear a new invigorating confidence in their words. It is truly a beautiful experience, one I experienced for the first time at thirteen when teaching nearly half of my class how to finish an especially difficult pre-algebra worksheet. In subsequent years I pursued other teaching opportunities and found fulfillment watching people grow and learn firsthand as a tutor. I learned the value of quality and consistent communication in teaching—that the whole process was easier and more successful for everyone involved when I spent time understanding a student's thought process, discussed concepts simply and concisely where possible, and adapted patiently and unjudgementally when needed.

My experience teaching in many settings, including as a teaching assistant for a GE introductory physics course, taught me to understand the diverse ways different people's minds solve problems. I discovered how truly intelligent so many people are, even when they arrive at all the wrong answers. As a physics class TA, however, I noticed that many of these intelligent people walked into class with the strong conviction that they would not be successful in a physics class. Some had barely passed (or barely survived) their high school physics class, and many had the impression that physics problems were the type of thing only untouchable geniuses could solve. On the occasions that these students came to me for help, I watched their confidence rise firsthand as they began to understand concepts and solve problems themselves.

I think that this simple observation underscores the purpose of physics education research. When we discover the best ways to teach physics, we discover the best ways to elevate others—by elevating their knowledge about physics, their confidence in themselves, their problem-solving abilities, and possibly their career opportunities. I find this purpose incredibly important, which is why I chose to focus my capstone project and report on a topic that I believe will contribute to this important field. I hope these findings will ultimately assist students in receiving as many of the benefits of a physics education as possible.

Introduction

The current field of physics education research is partially rooted in qualitative studies on metacognition from the mid twentieth century[1]. Teachers and professors tend to be most concerned with understanding how students go about solving problems, what an ideal problem-solving framework looks like, and how to encourage these strategies. One prominent method for both understanding and improving student problem-solving strategies is developing and implementing problem tutorials. Rather than typical in-class or homework assignments, tutorials are created to be detailed, interactive, and structured to help walk students through a problem.

There have been many attempts to implement physics problem tutorials in universities worldwide[2, 3, 4, 5]. While tutorials can vary widely in style, structure, and implementation, many are inspired by a set of undergraduate-level tutorials developed at the University of Washington in 2002 called *Tutorials in Introductory Physics*[6]. These tutorials have been implemented at many universities and are comprehensively a success. As is evident from the title, the tutorials were created with introductory-level undergraduate physics courses in mind.

To build on the success of many other tutorial studies, I have conducted research on the use of tutorials in upper-level undergraduate physics courses. Tutorials are typically catered to help students in introductory courses, so there exists a dearth of tutorial resources for professors and students in upper-level classes. Since prior research shows that graduate students tend to solve advanced problems less expertly than introductory ones[7], there seems to still be a need for materials that assist students in the problem-solving process beyond their first few semesters. So, I helped develop tutorials in a format which could be used flexibly across many different courses at different universities.

In creating a tutorial format that could fulfill these criteria and be maximally versatile and useful, we decided the format must incorporate a problem-solving framework, in full, that applies to a broad range of problem types, since problem-solving frameworks meaningfully impact learning and problem tutorials are often used to assist introductory physics students solve problems more conscientiously. [8,9] A five-step Minnesota model previously applied to intro-level physics[10] was suitable for this purpose. The five steps are as follows:

1. Useful Description (draw a picture, identify known, unknown, and target variables)
2. Physics Approach (identify the principles about which the problem is concerned)
3. Specific Application of Physics (applying principles correctly)
4. Mathematical Procedures
5. Logical Progression (check work)

With this framework in mind, several tutorial problems were constructed as models and adapted by professors to create a variety of different tutorials which were implemented in three sections of the same course from Fall 2022 to Spring 2024. The purpose of this capstone project is to evaluate the success of this format in this upper-level course.

Methods

In the process of developing problem-solving tutorials prior to this research, Physics 441, the first half of upper-level Electricity and Magnetism at BYU, was selected as the focus for the efforts of this project. All undergraduate physics majors are required to take this course, many in their last few semesters of college.

For the purposes of this project, tutorials were implemented in three iterations of this course. During each iteration, students who opted-in to provide feedback joined focus groups which were held throughout the semester or term. Each focus group covered ten questions which assessed the student's opinion of their problem-solving strengths and weaknesses, how they felt the tutorials affected their problem-solving strategies, etc. (See Appendix A). In the first iteration, during Fall 2022, eleven students from the course participated, and two tutorials were administered. During the second, in Fall 2023, ten students participated in full and four participated by survey only, and ten tutorials were administered. Finally, in the third iteration during Spring 2024, ten students participated in full and seven participated by survey only, and five tutorials were administered.

Focus group data for the first iteration was qualitatively analyzed using coding. Unfortunately, the only recordings available of these focus groups were video files that were difficult to automatically transcribe via software, so they had to be transcribed by hand. The videos of each of the five focus groups held during this iteration were coded in the following three steps:

1. Selective transcription: Rather than transcribing everything said in each focus group, the transcription was separated into ten categories, one for each of the main questions discussed. Only relevant answers were recorded, including exact quotes.
2. Prioritizing: Out of the transcribed information, keys were created to sort and pare down student feedback for qualitative analysis.
3. Pulling quotes: With transcriptions now effectively sorted, especially impactful quotes were noted. Each focus group video was reviewed a second time to ensure all quotes were correctly transcribed.

In the second iteration, I also worked as a teaching assistant for the class, assisting and observing in the implementation of a couple of tutorials as well as grading all tutorials by completeness, then scoring again strictly by accuracy for the purposes of this study. I was also granted access to student grades for the overall course.

In the third iteration, I held two rounds of focus groups, one mid-way through the course and another near the end, of which I recorded audio files for simplicity and transcribed using the Microsoft audio transcriber tool. Due to time limitations, I have restricted my qualitative analysis to pulling quotes from the focus groups that represent notable and/or consistent feedback.

Results and Discussion

Iteration 1

The focus groups conducted in each iteration, guided by the questions listed in Appendix A, presented students with a five-step problem solving model in reference to the Minnesota model. The participants were told to reflect on how they typically solve physics problems, and asked if there were any steps of the framework they typically handled well or struggled with. Later on, they were asked the same questions, with regards to how they approached tutorial problems specifically (Figure 1).

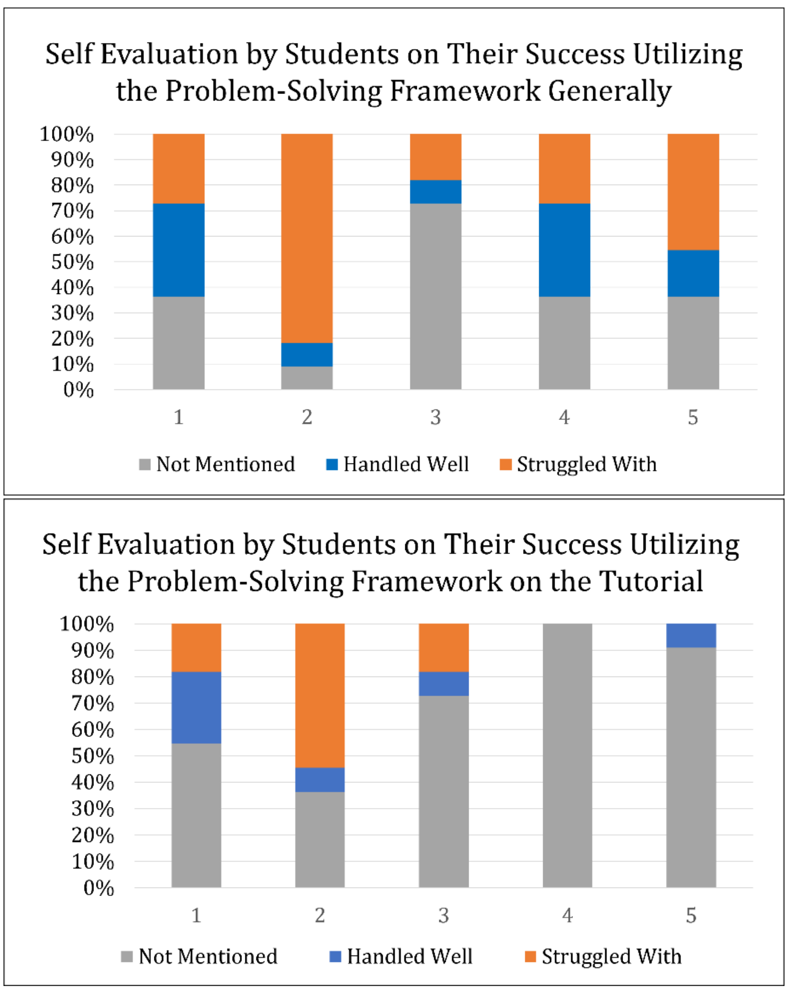

Figure 1: A comparison of student confidence on different steps of the problem-solving framework when asked about how they approach problems from class generally (top chart) and problems from the tutorials specifically (bottom chart).

Notably, when asked about how they approached tutorial problems, students had fewer responses overall about their utilization of the framework. Since students were asked to evaluate their performance within the framework generally (top chart) first, it is possible that students gave feedback for their work on the tutorials *in comparison* to their first answer about their work generally in class. In this regard, one might regard some of the non-responses in the bottom chart to mean the students performed similarly on tutorials to general class work. Considering that the tutorials offered less structure for the mathematical procedures, it could stand to reason that students do not report any significant changes to step four with regards to the tutorial problems.

However, even without assuming students interpreted the questions as a comparison, the fewer responses overall appear to account for significantly fewer responses of students struggling. It would be reasonable to conclude that the structure of the tutorials, which encourages students to draw pictures, write out relevant conceptual information, and work in small groups might help students stop struggling with these steps, but not necessarily enough that they consider those steps "handled well." This analysis is reinforced by the more focused responses students gave in reference to the group-work aspect of the tutorials, as illustrated in Figure 2.

Figure 2: Student opinions on assets to group work aspect of tutorials. Word size corresponds to the frequency each benefit was mentioned.

There are evident benefits students noticed consistently with regards to the group work aspects of the tutorials that imply a direct benefit to different aspects of the problem-solving framework. For example, several students noticed that they were better at checking their work in a group, one remarking that the format "forced" them to do so when they would normally abstain. This supports which would suggest that the tutorials helped at least a few students with step five of the framework. Students also seemed to appreciate brainstorming throughout all steps of the problem-solving, but most mentioned benefits from "bounce[ing] ideas off of each other" towards the beginning of problems, which might also correspond to students feeling more confident in their performance of the first two steps of the framework.

Iteration 2

To further assess the performance of the tutorial format, I went beyond student self-evaluations to explore the relationship between student performance on tutorials and overall success in the course (excluding tutorial grades). Figure 3 depicts this relationship, which a slight positive correlation. When the five students, who failed to submit one to three tutorials each, are included in this data set, the correlation is slightly stronger (R=0.699).

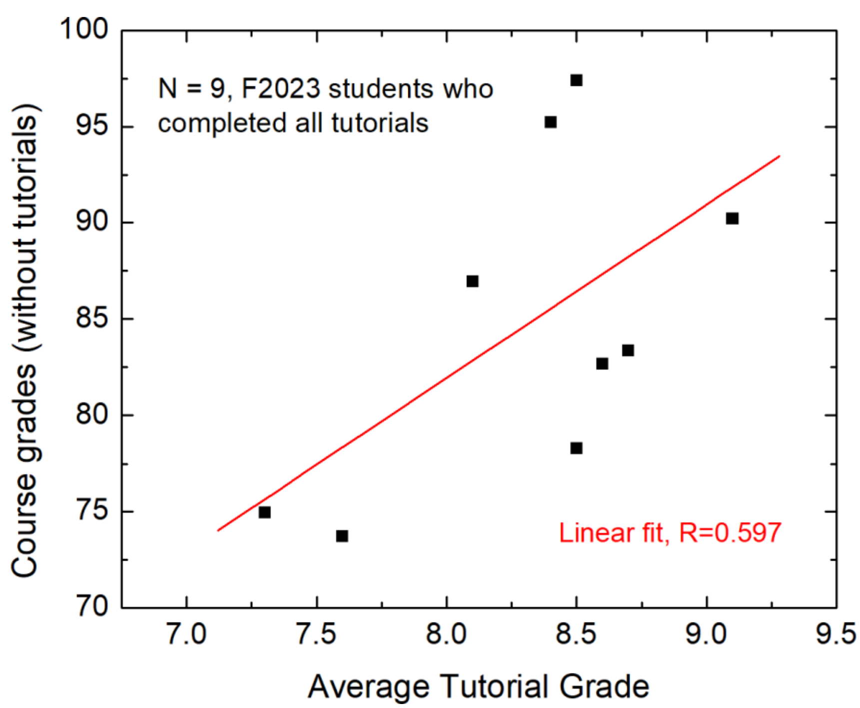

Figure 3 Plot of student course grades vs. average tutorial grades, excluding five students who did not submit all tutorials.

Iteration 3

While the focus group interviews from this last iteration have not been qualitatively analyzed to the same extent, there are a couple of significant quotes worth mentioning.

“I felt that the tutorial was expecting me to have some level of intuition that was not present.”
“The slightly less guided steps were difficult”

Both quotes are in reference to one particular tutorial that seemed to be conceptually difficult for multiple people and covered unfamiliar material. It should be noted that a stipulation of the tutorials’ success is that students must have enough information on the given topic to develop a sense of intuition and strengthen their problem-solving framework effectively.

“The framework…was helpful in remembering how to go about doing at least basic problems”

As many problem-solving frameworks and tutorials have been developed with introductory concepts in mind, it is not necessarily a surprise that this is a case. However, comments such as these are a good indication that using tutorials to review preliminary concepts students may have forgotten can be helpful in the beginning of an advanced course.

Conclusion

The primary purpose of this capstone project was to evaluate a new tutorial format created specifically for an upper-level physics course. That evaluation reads fairly favorably overall according to both student feedback and performance in the course. In its first implementation, students report a somewhat slight but still present improvement in their adherence to the intended problem-solving framework. This effect appears to be corroborated by the near-unanimous appreciation of the group work aspect of the tutorials by students, several of whom mention the collaborative aspects of the tutorials helped them practice certain steps from the framework. In its second implementation, a slight correlation was established between student tutorial grades and student overall course grades. This relationship insinuates that success on tutorials may serve as a helpful insight for course-correcting and greater success in the class as a whole. It may also insinuate that focusing on tutorial problems in class will have a significant effect on a student's grades on other assignments such as tests. However, to draw this kind of conclusion further research will be necessary to determine that this correlation does not simply arise from students focusing on succeeding on tutorials also being the type of student to focus harder or succeed on all their assignments independently of any benefits the tutorial itself provides. The third iteration also revealed some limitations of the tutorial format, including the amount of information students are provided with prior to or during the tutorial.

With further research and a more significant aggregate of information on student strengths and weaknesses confronting upper-level electromagnetics classes, this tutorial format could be developed into a set of cohesive problems covering topics that students most benefit from additional support with, which would be universally used and available. These tutorials could have the ability to unite physics educators, improve the experience of undergraduate physics students, and fulfill the need for more upper-level problem-solving resources.

References

1. Chandralekha Singh; Problem Solving and Learning. AIP Conf. Proc. 6 July 2009; 1140 (1): 183–197. https://doi.org/10.1063/1.3183522
2. Finkelstein, N., & Pollock, S. (2005, September 8). Replicating and understanding successful innovations: Implementing tutorials in introductory physics. Phys. Rev. ST Phys. Educ. Res., 1(1). Retrieved June 5, 2024, from https://doi.org/10.1103/PhysRevSTPER.1.010101
3. Passante, G., Emigh, P., & Shaffer, P. (2014, July 30-31). Testing Tutorials in Upper-Division: An Example from Quantum Mechanics. Paper presented at Physics Education Research Conference 2014, Minneapolis, MN. Retrieved June 5, 2024, from https://www.compadre.org/Repository/document/ServeFile.cfm?ID=13482&DocID=4081
4. Rudolph, A. L., Lamine, B., Joyce, M., Vignolles, H., & Consiglio, D. (2014). Introduction of interactive learning into French University physics classrooms. *Physical Review Special Topics - Physics Education Research*, *10*(1). https://doi.org/10.1103/physrevstper.10.010103
5. Avetyan, S. (2015). The undergraduate physics tutorial program at CSU los angeles assessment of utility and areas of interest (Order No. 3729376). Available from ProQuest Dissertations & Theses Global; Social Science Premium Collection. (1730285136). Retrieved from

https://byu.idm.oclc.org/login/?url=https://www.proquest.com/dissertations-theses/undergraduate-physics-tutorial-program-at-csu-los/docview/1730285136/se-2

6. Docktor, J., & Mestre, J. (2014). Synthesis of discipline-based education research in physics. https://doi.org/10.1103/PhysRevSTPER.10.020119
7. Mason, A. & Singh, C. (2010). Surveying Graduate Students' Attitudes and Approaches to Problem Solving. Physical review special topics. Physics education research. 6. 10.1103/PhysRevSTPER.6.020124.
8. Singh, C. (2016). Problem Solving and Learning. https://arxiv.org/pdf/1602.06352
9. Ferguson-Hessler, M. G. M., & de Jong, T. (1987). On the quality of knowledge in the field of electricity and magnetism. American Journal of Physics, 55, 492-497.
10. Docktor, J. et al. (2016). Assessing student written problem solutions: A problem-solving rubric with application to introductory physics. Physical Review Physics Education Research. 12. 10.1103/PhysRevPhysEducRes.12.010130.

Appendix A- Focus Group Questions

Here is an initial question to get you thinking about things.

1) In your view, what role do homework and tutorial problems play in helping you learn physics?

Consider the problems you've worked on in this class over the past month. You have been familiar, in some way, with the notion of a problem-solving framework in physics:

- Describe what is going on: draw a picture, identify knowns and unknowns, identify the target variable and other variables you might need
- Identify the principle or set of principles about which the problem is concerned
- Apply the principles correctly
- Use proper mathematical procedures
- Check your work and make sure your progression is logical

2) Is there a piece of this framework you have been able to handle well overall?
3) Is there a piece of this framework you have had a difficult time with overall?
4) Are there specific topics on which you performed well over the past month? For those topics, how well or not-well did this framework apply to how you handled those topics?
5) Are there specific topics on which you had a hard time over the past month (difficulty mastering it, or even just needing to apply more effort than usual to master it)? For those topics, was there a piece of this framework that made those topics a particular struggle?

Consider specifically the tutorials that you have been doing in the past month of the course or so. Take a minute to review these tutorials, if you need to recall them.

6) Considering the problem-solving framework you have just looked at, do you see any parts for which you think you individually did well on any of the tutorials from this past month?
7) Do you see any parts of the problem-solving framework that apply to what you individually struggled with on any of the tutorials from this past month?
8) Do you think any of the specific topics you covered in this past month's tutorial worked better or worse within the format given?
9) How do you think you would study the material for any or all of these tutorials in the future?
10) How do you think working in a group with your classmates helped you on any or all of these tutorials, if you did choose to work in a group?