Literature Review of Student Success in Statics Courses

Calvin Cuddy[1], Dr. Jessica Deters[2]
1: Undergraduate Researcher, Department of Mechanical & Materials Engineering, University of Nebraska-Lincoln
2: Assistant Professor, Department of Mechanical & Materials Engineering, University of Nebraska-Lincoln

Abstract

This literature review is part of a larger project aimed to improve statics student success at the University of Nebraska-Lincoln. This paper is an examination into methods of increasing outcomes and student success in Statics. An analysis of 45 papers was completed, 23 of which showed positive results by various methods with quantitative analysis. The data collected was sourced from a total of 3 scholarly databases, utilizing 26 keywords. The most successful intervention (measured as percentage of positive results from articles analyzed) was supplemental instruction. However, methods such as supplemental online resources, rapid in-class feedback/ adapted class structure, and hands-on work/assignments appeared to be effective. Overall, there are many methods that work for increasing student outcomes, and instructors should tailor them to their institution's needs.

Keywords

Statics, Undergraduate Research, Mechanical Engineering, Student Success

Introduction

Statics, which primarily focuses on the study of rigid bodies in equilibrium, is a core engineering course for many disciplines, including mechanical, civil, and construction engineering. Across universities, statics courses commonly have a high DFW rate (drop, fail, withdraw rate), and low knowledge retention. This problem poses the research question- what kinds of interventions are most effective at improving student outcomes in statics? To understand the struggles within the course content and measures to improve them, a literature review was conducted. All sources were found using scholarly databases, including ASEE Peer, UNL Libraries, Google Scholar. A combination of the following search terms was used to identify articles for review: "Statics Mechanics Student Success Results Outcomes Performance Improvement Redesign Data Hands-on Flipped Online Resources Supplemental Instruction Peer-assisted Labs Homework Help Study Groups Writing Assignments Recitation Course Material Comparison". Some topics may not be fully represented, as this review is not intended to be fully comprehensive but rather to provide an overview of different intervention styles and their effectiveness. Articles were selected for inclusion based on their relevance to the research question.

General Findings

Overall, there are many effective ways to improve student success/outcomes in statics. Through this literature review, we found that there is no "perfect" solution, and that students and faculty at different institutions respond differently to different interventions. Therefore, an ideal intervention would involve research and feedback on a smaller scale, from institution to institution. Each institution should weigh the options to decide which intervention fits best within their context. In this literature review, 45 papers and articles were analyzed, and a total of 23 papers and articles had positive results indicating student outcomes were improved. The aggregated data is summarized in the following tables. The differing interventions were grouped into "intervention styles", as shown in Table 1. From Table 1, it appears that supplemental instruction, online resources, in-class structure, and hands-on are the most consistently effective interventions. Supplemental instruction has the highest amount of data points, and the highest percentage of positive results. Table 2 aggregates all the positive result data. The key takeaways section was designed by Author 1 to describe any novel data that each intervention may have revealed- it is not intended to empirically represent each article as a whole. A more in-depth look at each "intervention style" follows.

Table 1. Impacts of intervention styles

Intervention style	Positive impact on outcome	No/Negative impact on outcome	No outcome results	Total	Percent positive results
1. Course material delivery	2	2	1	5	50.00%
2. Writing	2	2	0	4	50.00%
3. Additional exposure	2	3	0	5	40.00%
4. Hands-on	3	1	2	6	75.00%
5. Online resources	3	1	3	7	75.00%
6. In-class structure	3	1	2	6	75.00%
7. Supplemental instruction	6	1	0	7	85.71%
8. Course material	1	1	0	2	50.00%

Note: WMU's blended style is included in both additional exposure and course material delivery
Percent positive results calculation excludes "No outcome" results column

Table 2. Positive results summary/takeaways

Intervention	Style	Institution	Results	Key Takeaways
Blended style learning with recitation implemented	1/3	Western Michigan University	Higher pass rate, mean final course grade, pass rate in future course [1], [2], [3]	Final course grades shouldn't be the only metric of success for an intervention
Differing presentation styles	1	University of Cincinnati	Higher final course grades [4]	Supplemental online resources can be extremely beneficial
Process problems (Write-to-learn)	2	Virginia Tech	Higher SCI normalized gain [5]	Higher SCI scores does not always lead to a higher course performance
Process problems (Write-to-learn)	2	Hofstra University	Higher final course grades [6]	Prerequisite course grades should be considered in analysis of outcomes
Recitation	3	Penn State Behrend	Higher passing rates among at-risk students [7]	Higher performing students benefit less from recitation
Labs	4	Oklahoma State University	Higher homework and average exam scores [8]	Success of the labs is attributed to student approval/engagement
In class hands-on modeling/activity sessions	4	California Polytechnic Institute	Lower failure rates [9]	If adding additional contact time, hands-on activities can be beneficial

Intervention	Style	Institution	Results	Key Takeaways
Project-based hands-on homework	4	University of Central Florida	Higher midterm scores on topics focused in projects [10], [11]	Projects may only help students in a direct application of the same topic, but will not carry over to other topics
MasteringEngineering	5	Colorado School of Mines	Higher midterm and final exam scores [12]	MasteringEngineering is an effective homework tool
Interactive online games	5	University of Missouri-Rolla	Higher scores on single question quizzes [13]	Games can be a great study tool for tough concepts that require repetition
Computerized assessment systems	5	EAFIT University	Higher final course grades and lower failure rate [14]	Similar to games, this system is a good tool for concepts that require repetition
Rapid in-class feedback	6	Rowan University	Higher quiz scores [15]	In class MC questions/rapid feedback has overwhelming approval and facilitates peer discussion
Rapid in-class feedback, group projects	6	North Dakota State University	Higher attendance [16]*	Although the outcome data is not present, students had higher attendance and engagement
In class group worksheets	6	University of Toledo	Higher scores on previous semester assessments [17]	Group collaboration increases conceptual/content knowledge
In class group worksheets with Learning assistants	6	University of Colorado Boulder	Positive student perception and higher interaction [18]*	Learning assistants can be a great low stakes resource for students
Pre-lecture quizzes, in class group problems, optional final, other minor changes	6	University of Louisville	More favorable grade distribution (with exception to F grades) [19]	It is difficult to cater an intervention to benefit all ranges of students
Supplemental instruction sessions	7	Louisiana State University	Higher passing and ABC passing rates [20]	SI sessions can be helpful to make students feel accepted and comfortable seeking help
Supplemental instruction sessions	7	University of North Carolina Charlotte	Lower DFW rates, higher retention rates [21]	SI sessions can increase student retention rates
Supplemental instruction sessions	7	Mercer University	Higher exam 1/2 scores, lower exam 3/final exam scores [22]	Mandatory attendance for SI sessions can negatively impact outcomes and student perception
Supplemental instruction sessions, adapted class structure	7	Queensland University of Technology	Higher aggregate core of quizzes, project, exam [23]	Majority of students utilize SI Sessions as their most useful study tool
Faculty-led study groups	7	Wentworth IOT	Higher final course grades [24]	Students participating in study groups perceive that they are part of a learning community
Supplemental instruction sessions	7	Rensselaer Polytechnic Institute	Lower D and F grade rates [25]	Students require smaller group, longer sessions to reap the benefits and cover all the material
Worksheets tailored to common misconceptions	8	Hamburg University of Technology	Higher scores on SCI [26]	Design intent with worksheets/recitation structure is extremely important

*Excluded from Table 1, does not directly apply to outcomes

1. Flipped Learning Style (Course material delivery)

Many programs have opted to utilize a flipped learning style in their statics courses. Typically, lecture videos are posted online prior to the class meeting. The purpose of this intervention is to increase exposure to material, considering the amount of time spent covering theory, derivations, and lecture material during contact time is substantially less. This leaves the entire duration of the class meeting for discussion and problem-solving. Despite the additional time spent, the outcomes do not improve significantly [27]-[29]. There are few cases of positive results, however. Western Michigan University had success in improving course passing rate, mean final grade, and performance in subsequent courses from flipped style learning with recitation implemented [1]-[3]. Finally, the University of Cincinnati showed a significant difference in final grades between their flipped section compared to a traditional section [4]. A common theme within these articles is the lack of student motivation to watch videos and show up to lectures. It appears that many students do not feel like they have the time to both watch the lecture videos outside of class and to show up to the "problem solving" contact class time. Therefore, instructors who are considering implementing a flipped classroom should be mindful of these motivation and workload drawbacks in their course design.

2. Writing

Many institutions explored the benefit of writing for conceptual understanding. One common intervention is "Writing-to-Learn" assignments, where the student describes their process for solving a problem in writing. It is believed that if you can describe the problem-solving process, it will help you have a deeper understanding of said process [30]. This was typically accomplished by selecting one homework question from each regular assignment to be described via the writing-to-learn style. Writing interventions were shown to have mixed results. In two cases, writing interventions did not have a significant impact on student outcomes, while in two other cases writing interventions were found to have positively affected Statics Concept Inventory scores and final course grades [5], [6], [30], [31]. Instructors should be mindful of the mixed nature of the results while considering writing implementations.

3. Additional Exposure

Additional exposure refers to an additional class contact time, but typically is achieved by the addition of recitations. Recitations are commonly used to give students more exposure to material at a smaller, more personal setting, usually led by undergraduate or graduate students. Recitations are common for first- and second-year intensive stem courses such as Calculus, Chemistry, or Physics. Interestingly, the implementation of recitations does not appear to significantly increase outcomes [32], [33], with exception of passing rates for at-risk students in one case [7]. As previously discussed, Western Michigan University found benefits in a flipped learning with recitation implemented, [1]-[3]. Aside from recitation, The US Naval Academy experimented with the addition of an extra hour of instruction. The difference between this and recitation is that their additional contact time was unstructured and left to the discretion of the instructor. They found an insignificant difference between final exam scores and course grades between the experimental and control groups [34]. Based on this data, recitations appear to be beneficial to at-risk students.

4. Hands-on/ Lab

Hands-on learning and labs have been shown to be an effective method to enhance learning in STEM courses. The purpose of hands-on/lab enhancement is to enrich student learning by introducing a tangible application of the concepts discussed in lecture. However, it is not widely used among statics courses. Oklahoma State University implemented 3 hands on, group-based labs with worksheets. These labs focused on core concepts such as particle equilibrium, trusses, and static friction. They found that exam scores among those concepts significantly increased, along with an overwhelming amount of student approval and requests for more labs [8]. Similarly, Cal Poly implemented an extra hour of contact time dedicated to modeling/hands on activities with an associated homework. They found a positive impact of the additional contact time on decreasing failure rates. Students also indicated these activity sessions as a key component in their understanding of the material [9]. Another common hands-on method is utilizing projects. Colorado State University implemented group-based projects, including design, demonstration, and analysis. They found no significant impact on the Concept Assessment Tool for Statics (CATS) [35]. The University of Central Florida utilized project-based hands-on homework, involving the creation, experimentation, and analysis of a physical model with an associated video and report. They found a significant impact on exam scores, but only for the topics covered by the projects [10], [11]. Overall, it seems hands-on methods can be very effective. The major drawback to this style of intervention is resources- allocating lab time/resources can be expensive as well as designing and grading hands-on projects or homework. If your institution has the necessary resources, hands-on interventions could be very effective if they are implemented well.

5. Online Resources

Another widely used intervention is the implementation of online resources. This typically includes some form of additional resources, but can include a replacement of previously offline resources. For example, the Colorado School of Mines replaced their pencil and paper homework with an online integrated homework/textbook system, MasteringEngineering. They found that students performed significantly better on midterm and final exams for both Statics and the subsequent course, Mechanics [12]. An additional benefit of online homework is instant feedback, along with less time spent on grading. Another interesting intervention was interactive online games. The University of Missouri-Rolla implemented games for two common struggle topics- centroid and moment of inertia. They found significant improvement in these topics in quizzes. Students rated the games as “significantly more effective than the textbook as an aid in learning the material” [13]. Kettering University focused problem areas in a similar way, but with online learning modules rather than games- covering 7 units in 20 modules. However, they found no significant impact on exams scores [36]. Another method with promising results was a computerized assessment system at EAFIT university. This was an automized, random generation of customized practice tests- based off user inputs. The parameters include context, variables, tasks, topics, and problem types. They found this to have significant benefits towards final course grades and failure rates. They do not compare the course structure between intervention and control, and they note that examination methods were different between the groups- so the results should be taken with a grain of salt [14]. Online resources could be useful for institutions that only want to invest resources into the program once. That is, they could create or adopt an online system, and it could continue to benefit the course long after the initial investment.

6. In-class Structure

Modifying the in-class structure of the course is another intervention style that some universities implemented. One strong example of this is the inclusion of “rapid feedback”, or in-class concept checks. Essentially, students are posed an in-class question, and expected to answer within a given time frame. Answers are recorded either by online tools or visual surveying of flashcards. The answer is then revealed and discussed. The driving motivation behind this intervention is that students apply concepts immediately, rather than later in the homework, which will ultimately benefit their retention. Rapid feedback has been proven to increase quiz scores and attendance at Rowan University and North Dakota State University respectively [15], [16]. Students also showed extremely high support for these methods, and peer to peer discussion was increased. Similarly, other institutions have included in-class worksheets. At the University of Toledo, they found that these in class, peer-assisted worksheets improved student scores on assessments. They spent 15 minutes in class on each worksheet. Each worksheet was specifically designed to align with core statics conceptual problems, and act as “scaffolds that help students identify the relationships between different pieces of information and concepts required to solve a problem. They would utilize the “think-pair-share” strategy to facilitate discussions [17]. An important aspect of both rapid-feedback and in-class worksheets is that they utilize peer assistance and discussion. This is tied to the fundamental benefit of supplemental instruction sessions- peer assisted learning. This intervention is a good option if you do not want to allocate any more resources to the program- so long as you can allocate some in-class time.

7. Supplemental Instruction

Supplemental Instruction is a model that utilizes peer-assisted learning to enhance student learning, success, and retention in courses. This can be implemented in many ways, but typically it involves Supplemental Instruction (SI) sessions- voluntary “help-sessions” for students that would like questions answered, or more practice. The difference between these sessions and additional exposure/recitations is subjective, but interpreted by Author 1 as follows: recitations are more formally structured, and typically contribute towards the final grade and/or are mandatory. Another key difference is the emphasis on peer-assisted work rather than independent work. These are typically facilitated by undergraduate students but could also include faculty or graduate students. For example, at Rensselaer Polytechnic Institute they structured the SI sessions as follows: the session starts with a review sheet from previous lectures. Students would then work on an “informal quiz” (low stakes, previously prepared questions). Afterwards, students were asked to pitch in questions they would like to go over. In addition, students completed mock exams, games, and real-life application problems. They also integrated “study skill strategies”, with the intention to improve reading, note taking, time/stress management, memory, and test taking skills [25]. These SI sessions have been proven to produce many benefits, including improved passing rate, increased final test/course grades, and decreased DFW (drop, fail, withdraw) rates [20]-[25]. Students also reported benefits such as the sessions being a useful study tool, helpful in organization of content, and an increased sense of community. However, one example did find no significant impact on final course grades [37]. Students also reported benefits such as the sessions being a useful study tool, helpful in organization of content, and an increased sense of community. There are some other interesting findings from other papers. For example, Mercer University found that mandating attendance had a negative effect on students, stating that on some intervals students who did not attend sessions scored better even after the grade penalty [22]. Considering the availability of articles and papers supporting positive results from the implementation of supplemental instruction, it could be an effective intervention for institutions willing to organize such a program.

Other

There are many other miscellaneous methods that are otherwise not well represented in the literature. For example, Worcester Polytechnic Institute experimented with multiple exam sittings- leaving you time to learn from your mistakes before taking the exam again, so you have a chance to improve your scores. Their qualitative results (surveys) were favorable [38]. Another example is the addition of graphical statics at the University of St. Thomas and University of South Carolina, which emphasized vector addition, force polygons, and funicular polygons. They compared results using the Statics Concept Inventory and found no significant impact. However, they noted that students' accuracy in drawing free-body diagrams had improved [39]. Hamburg University of Technology utilized the Force Concept Inventory in conjunction with interviews to design worksheets based on common misconceptions and errors. The worksheets employ the strategy "elicit, confront, resolve". To evaluate the effectiveness, they used the Statics Concept Inventory (SCI). They found that scores on the SCI were significantly higher than previous sections [26]. Additionally, Wentworth Institute of Technology has implemented SolidWorks as a graphical tool to help students visualize statics concepts [40]. Central Connecticut State University has used Matlab as a graphical user interface designed as a supplemental online resource [41]. Overall, I believe it is important to keep an open mind while investigating what intervention would work best for your institution. Ideally, anything can benefit the program so long as it has support from the students and faculty.

Summary

When faced with the research question, "What can be done to improve student success/outcomes in statics without decreasing expectations?", there is no simple answer. Effectively increasing student outcomes in a statics course can be done in many ways. Some of the most consistently effective methods include supplemental instruction, supplemental online resources, in-class structure, and hands-on work/projects. Through this literature review, we found that there is literature that both confirms and contradicts the benefits of most interventions, some with more favorable results than others. Therefore, one must investigate on an individual institution basis what might work best for their faculty and students. However, if one wanted to judge based purely off the literature, supplemental instruction has the most favorable outcomes. This is considering that it has the most literature available, and the best ratio of positive results to negative results.

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Calvin Cuddy

Calvin Cuddy is a 3rd year Mechanical Engineering student at the University of Nebraska-Lincoln. He is an Undergraduate Researcher under Dr. Jessica Deters at the Department of Mechanical and Materials Engineering.

Dr. Jessica Deters

Dr. Jessica Deters is an Assistant Professor of Mechanical and Materials Engineering and Discipline Based Education Researcher at the University of Nebraska - Lincoln. She holds her Ph.D. in Engineering Education and M.S. in Systems Engineering from Virginia Tech, and her B.S. in Applied Mathematics and Statistics from the Colorado School of Mines.