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Engaging Mechanics of Materials and Dynamics Students in Designing Curriculum for Statics

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Engaging Mechanics of Materials and Dynamics Students in Designing Curriculum for Statics

Abstract

Statics is a common sophomore level course that for many students is their first engineering applied physics course. This introduction to engineering mechanics serves as a prerequisite for mechanics of materials and dynamics. Students often struggle in statics as they are exposed to the content for the first time, but typically develop better statics problem solving skills in the subsequent courses of mechanics of materials and dynamics.

The purpose of this study was to access the insights that students in mechanics of materials and dynamics have when reflecting back on their statics curricula with the goal of leveraging those insights as an opportunity for students to develop learning activities or aids that they would have wanted in their statics course.

Thirteen students enrolled in a summer term of mechanics of materials or dynamics were tasked with developing a learning activity or aid for a statics topic that they initially struggled with, but self-perceived that they had gained a better understanding of. These students were interviewed multiple times throughout the summer term to gain insight into their perspectives, thought processes, and decision making during their curriculum design process. Participating in the interviews and providing their learning activity or aid contributed towards 10% of their final mechanics of materials or dynamics grade. The interviews were recorded, transcribed, and thematically coded for data analysis.

All thirteen students expressed a gained appreciation for the challenges of designing curriculum with common sentiments towards how to design something that is beneficial to multiple different learning styles and developing empathy for their instructors and their curricular decisions. As one student said in their final interview, "…it does take a lot of time to translate the information so that it's understandable for every person. I appreciate a lot of what the teachers do to make it simple enough for every student to grasp the concept." Two of the thirteen learning activities/aids created by the students were selected by the statics instructor to incorporate into their future statics courses.

Students often have little influence on the curriculum used in the classroom, but as recipients of that curriculum, they have valuable opinions that are often only captured in course evaluations. Engaging students to develop curriculum that they think would have been helpful to their learning provides them with an opportunity to enrich their own understanding of the material, potentially create something that can be used to help future students, and develop a greater appreciation for the challenges faculty encounter when designing curriculum. Similar projects can be incorporated in other post-requisite courses to gain these benefits in other disciplines. Future work on this research will aim to develop a framework and rubrics for the project that can be easily adopted in any post-requisite course for those interested in doing something similar.

Introduction

The goals of this study were to provide students enrolled in post-requisite statics courses an opportunity to develop learning activities or aids for future statics courses while exploring

their perspectives throughout their curriculum design process. Providing students an opportunity to develop a learning activity or aid for one of their previous courses can have multiple potential benefits for students and instructors. First, and perhaps most obvious, is students will likely improve their own understanding of topics in the previous course [1-3]. Second, instructors may gain a learning activity or aid that they can adopt in their future courses. Third, and perhaps most beneficial, is improved relationships between students and instructors [4]. Instructors may gain insight into the learning activities or aids that students want and students potentially gain a deeper respect for the challenges instructors face when designing curriculum.

To further explore these potential benefits, thirteen students enrolled in either a summer offering of mechanics of materials (MoM) or dynamics were interviewed multiple times throughout a course project asking them to design a learning activity or aid for a specific statics topic of their choice. While the range in quality of what these students designed varied considerably, they shared similar sentiments in their goals for their designs and all thirteen expressed a greater empathy towards the challenges their instructors encounter when designing curriculum. Ultimately, the statics instructors at the institution where this study took place were interested in adopting two of the learning activities designed by these students and have so far implemented one in their statics course multiple times.

Student input on curriculum has typically been limited to end of term course evaluations [5-6], a task that they are not perceived as having the pedagogical expertise to do well [7], let alone design curriculum [1,6,8]. However, students can add valuable contributions to curriculum given the opportunity [1-2, 9-11], and this study has demonstrated that students can potentially develop curriculum that instructors are interested in adopting. That being said, the authors contend the main benefits of providing students the opportunity to design curriculum is the potential to improve student understanding of course topics and the increased empathy students develop for their instructors.

Background

Statics is a common sophomore level course for civil (CE) and mechanical engineering (ME) students. It is typically their first engineering mechanics course and serves as a prerequisite for MoM and dynamics, which are subsequently prerequisites for many upper-division CE and ME courses. Therefore, statics is one of the most important fundamental courses in a CE or ME student's education. Many students often struggle with multiple topics in their statics courses, which can impede them from advancing into post-requisite courses and continue to challenge students that do advance [12-13]. Even students that excel in statics do not develop complete mastery of statics topics in their statics course, but in the post-requisite courses that build upon statics concepts [14].

Therefore, students in statics post-requisite courses, like MoM and dynamics, have more valuable opinions on statics curriculum for instructors than students providing feedback at the end of their statics course. As MoM and dynamics students become more confident with topics they initially struggled with in statics, they are more likely to have a reflective perspective towards these topics. This perspective gives them valuable insight into how they might teach

themselves those statics topics if they had to go back and take statics again. The aims of this study were to leverage those insights by providing a project for MoM and dynamics students to design a learning activity or aid for a statics topic they may have struggled with initially but had developed enough confidence in to develop curriculum for.

Student perspectives on curriculum design are almost exclusively reserved to end of course evaluations with little to no incentive for instructors to incorporate that feedback in future course offerings [5-6, 15]. Students are rarely provided the opportunity to create potential curricular activities for adoption in courses, mostly because they are not trained in curriculum development [1, 5, 8, 16]. This barrier to including students in curricular design, however, is limited to focusing on the sole output of something adoptable by instructors while ignoring potential other benefits to providing students the opportunity to design their own learning activities or aids. For example, the benefits of learning through teaching are well known [17-18] and instructors develop a much richer and deeper understanding of the material they teach through their curriculum design process [1-3, 5, 9-10, 19]. Therefore, the authors believe it is worthwhile to provide students opportunities to develop their own learning activities or aids to foster student growth in understanding of previously learned content. If the students happen to develop something worthwhile of adoption, then that is an additional benefit.

The opportunity in which the authors provided students to develop statics curriculum was in two different summer courses. One being a MoM course offered in the summer of 2023 and another for a dynamics course offered in the summer of 2024. Both courses were offered over a 6-week summer term aimed at providing students who passed statics late the opportunity to catch up and stay on track to graduate. During the 6-week term, both classes met for 3.5-hours twice-a-week. There were five students in the MoM course and eight students in the dynamics course. The statics curriculum design opportunity was incorporated in both courses as a project worth 10% of their MoM or dynamics grade. 10% was chosen to strike a balance between making the project weighted enough for the students to take seriously, while also acknowledging that designing curriculum for statics should not make up a substantial portion of a MoM or dynamics grade even though these courses continue to utilize and build upon several statics concepts. Results from the summer 2023 MoM course led to some changes being made in how the project was facilitated and studied in the summer 2024 dynamics course, which are presented in the next section.

Methods

The first iteration of this statics curriculum design project was implemented in the summer 2023 MoM course. The first author was the instructor for the course and presented the project to the students on the first day of class. Students were presented with a list of statics topics and encouraged to choose a topic they previously struggled with but felt confident enough in now to develop a learning activity or aid for. The students were informed that a learning activity could be something statics students do in or outside the classroom and a learning aid could be a tool that helps students understand a concept or solve a problem. Students were informed of the project weight and that grading would be participation-based with the expectation that they participate in two interviews and provide a physical deliverable of their

learning activity or aid at the end of the term. Students were asked to schedule their first interview within the first week of class and bring potential ideas for their project to the interview. The second interview was scheduled at the end of the term and students were expected to bring their project deliverable to the interview to help facilitate the discussion of the learning activity or aid they created.

Both interviews were semi-structured to facilitate a consistent set of questions for each student, while also allowing the interviewer to ask unique follow-up questions catered to each student and their learning activity or aid [20-21]. Interviews were chosen for data collection as they allow for access to the students perspective and thought processes on the curriculum development process with their own vocabulary [21-22]. The interviews were conducted by the first author, who as previously mentioned was the instructor of the course. The authors were aware that this decision to have the instructor of the course interview their students for a project that is part of their course grade may bias the students' responses. For example, the students may answer interview questions in a less authentic way in an attempt to impress the instructor. To help mitigate this, the instructor informed the students at the beginning of both interviews that they were not being graded on their responses. Furthermore, the decision to have the instructor interview the students was made because the instructor would have greater rapport with the students and more specific insight into each students' learning activity or aid through informal interactions in class and office hours than an outside researcher would [20, 22].

Two major methodological changes were made for the summer 2024 dynamics course. The first was adding a third interview to the middle of the term to help maintain the students' progress on their project and provide feedback on a draft of their learning activity or aid. The desire for a midterm check-in interview was expressed by all five 2023 MoM students in their final interview and the instructor observed that such a check-in would have likely improved the quality of their final deliverable.

The second change made for the summer 2024 dynamics students was that their interviews were not conducted by the instructor. Instead, the second author taught the dynamics course and the first author conducted the interviews. The authors wanted to keep the first author in the interview role to build on and leverage their interview experience with this project from the previous year [23] and to help manage the workload of the second author who had been assigned to teach dynamics for the first time. A summary of these changes is provided in Table 1.

Table 1. Methodological changes made across terms

Course	Term	Instructor	Interviewer	# of Interviews	# of Students
MoM	Su '23	First author	First author	2	5
Dynamics	Su '24	Second author	First author	3	8

Summer courses were chosen for the first two iterations of this project because they typically have smaller class sizes that allowed for the first author to manage conducting multiple interviews with each student. All the students enrolled in both the MoM and dynamics courses participated in the project. All the students were ME or CE majors except one biomedical engineering (BME) student. This study was approved by the Institutional Review Board (IRB00006544) at the institution where the courses were offered. A demographic summary of the students and their learning activity or aid is provided in Table 2.

Table 2. Student demographics and their designed learning activity/aid. Modified from [24].

Course	Gender	Major	Learning Activity/Aid
MoM	F	CE	Pegboard for visualizing moment direction
	M	ME	Paired method of sections analysis of Steel Bridge Competition entry*
	M	CE	Flipped classroom with YouTube videos on vector addition
	F	ME	Checklist for solving 2D equilibrium
	F	CE	Flowchart for solving moment equilibrium
Dynamics	F	CE	Flowchart for when to do method of sections or method of joints
	M	ME	Homework asking students to draw FBDs for a real-world frame and machine with help from YouTube videos.
	M	CE	Method of sections problem that emphasizes importance of identifying zero-force members
	M	ME	In-class activity comparing the clamping force for three different pliers
	M	ME	Flow chart for calculating centroids
	F	BME	In-class activity on calculating tension in bicep during dumbbell curls
	M	CE	Trigonometric Identities Reference Sheet
	M	ME	Marshmallow and skewer truss model to visualize tension/compression members*

*****Indicates learning activity/aid was or will be adopted by statics instructor.

Each interview was typically 30-60 minutes and audio-recorded with each student's consent and then transcribed by a third-party transcription service for later data analysis. Sample questions from each interview are provided in Table 3.

Table 3. Sample Interview Questions

Interviews	Sampled Structured Questions
Initial Interview	• Was there a method of teaching from another statics concept/topic or another course that you particularly liked? Why? Do you think you could replicate this for your chosen concept/topic? • Do you think students can have a role in curriculum development? Should students have a role? • What benefits/challenges do you foresee with including students in curriculum design?
Midway Check-In Interview	• Questions for this interview were uniquely catered to each student's learning activity/aid and aimed to help the students make progress on their design.
Final Interview	• What improvements do you think could be made on your curricular activity? • What about the curriculum development process do you now know more about than before this project? • What about your curriculum specifically do you find beneficial for you as a learner?

Data analysis involved a series of both inductive and deductive coding of interview transcripts [20]. Immediately after each interview the first author would inductively code the interview transcripts to identify follow-up questions for subsequent interviews and begin identifying emergent themes [22-23]. The authors also had two undergraduate research assistants employed during the summer 2023 MoM course who inductively coded the transcripts for the five MoM students. While this was the undergraduate research assistants first time coding interviews, both authors regularly met with them throughout the summer to train them in the coding process and discuss emerging themes and potential different interpretations [23, 25]. Their perspective as students who could more closely relate to the participants was valuable in providing interpretations the authors might have missed. Although these two undergraduate research assistants were no longer employed during the summer 2024 dynamics course, their work in the initial phase of this study strengthened the reliability of the codes identified for the five MoM students that were later applied to the eight dynamics students' interviews.

After all the interviews were conducted for each participant, the first author would deductively code all of that participant's transcripts using the emergent themes from the first round of coding. This process helped determine if the themes initially identified could be consistently found within and across participants' interviews [20, 25]. While this coding process sought to identify themes across the participants, the sample size of thirteen is too small and specific to make broader transferable claims about students designing curriculum. Rather, identifying themes from the first two offerings of this project was intended to inform how to improve future offerings of this project and eventually guide the development of a framework to help facilitate other instructors wishing to implement a similar project in their post-requisite courses.

Results and Discussion

Initial findings from the summer 2023 MoM offering were reported in a previous paper [24]. Therefore, the results in this paper will primarily focus on the findings from the summer 2024 dynamics offering. Also, our three primary objectives for providing students the opportunity to develop their own curriculum were: 1) help students improve their understanding of statics topics, 2) potentially provide our statics instructors adoptable new curriculum, and 3) instill an appreciation for the challenges of curriculum design and develop empathy for instructors amongst our students. While all the students expressed that their curriculum development process improved their understanding of their chosen statics topic, truly assessing this is beyond the scope of this paper. It can be broadly assumed that learning did occur to some extent based on the principles of learning through teaching and developing curriculum [1-3, 5, 9-10, 17-19]. As the student that developed the flowchart for centroids said in their final interview:

> *"I think it [developing their flowchart] was just a good refresher because I kind of forgot about how to do it. Relooking at it, I understood it a little better now than previously."*

If nothing else, this project requires students to go back and revisit statics topics in a more in-depth way. The process of developing a flow chart, which was a learning aid developed by three of the students, requires developing a richer understanding of the steps and nuances involved in solving specific types of problems [26].

Regarding the second objective, two of the students developed a learning activity that the statics instructors wanted to adopt. The steel bridge truss activity has been implemented already over two terms of statics and the marshmallow skewer truss will be implemented in the fall 2025 offering of statics. More information on the steel bridge truss activity can be found in the previous paper about the initial offering of this project [24]. The marshmallow skewer truss can be seen in Figure 1.

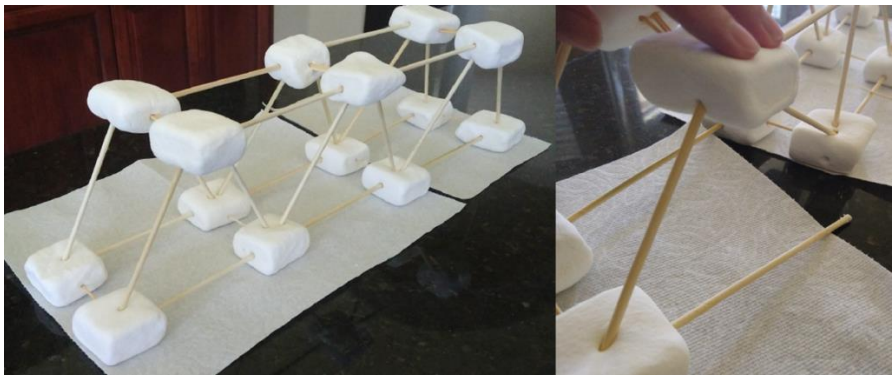

Figure 1. Marshmallow skewer truss (left). Skewer being pulled out of marshmallow when hand presses down on top of truss indicating skewer was in tension (right).

The student that developed the marshmallow skewer truss exercise envisioned that students would make the truss in class, mark the skewers with a permanent marker just outside the marshmallow joints, make predictions on which members would be in tension and compression for a specific type of loading, and then load the truss accordingly and observe which members

are in tension or compression depending on whether the mark moved away from the marshmallow or into the marshmallow, respectively. In their third interview they stated their goal for this to be a visual, qualitative exercise:

> *"This could serve as a visual aid without the hardcore math applied. I just want the students to actually see truss analysis, but put into practice in a concrete form rather than just looking at pictures and trying to solve for what's given all the time."*

While 2 out of 13 learning activities/aids being adopted may not seem like a strong endorsement for students designing curriculum, much of what was developed has the potential to be implemented with some adaptations and building upon the students' original ideas. For example, statics students could be given an assignment to develop their own flow charts for a deeper understanding on a specific topic [26] rather than being given a flow chart developed by a student that participated in this project.

The remainder of this section will focus on the findings related to the third objective. The two most common themes that emerged from the interviews regarding this objective was students desire to develop something that accommodated multiple learning styles and a new found appreciation for their instructors and the challenges of developing curriculum. One student emphasized both these themes in the following excerpt from her final interview:

> *"…it does take a lot of time to translate the information so that it's understandable for every person. I appreciate a lot of what the teachers do to make it simple enough for every student to grasp the concept."*

In regards to learning styles, while there is little to no evidence to support that catering instruction to a student's learning style improves learning [27-28], belief in this idea is considerably widespread amongst students and educators [29]. The prevalence of the student participants' desire to accommodate learning styles further demonstrates this common belief. This desire to develop something that accommodates multiple learning styles caused some students to struggle with getting started on their design. This struggle was expressed by a student who came to their first interview unsure on what they wanted to design:

> *"I think the biggest challenge is I want to produce something where everyone can understand. But the challenge is to get over that. Everyone's different; everyone has a different learning style."*

At the same time, the desire to accommodate different learning styles provided motivation and excitement for some of the students in their approach for this project. As another student said in their first interview:

> *"I know for a fact I'm not a lecture learner. I've tried it. It's the very basic one that everyone does and that's why I know that it doesn't work. So I want to make something that's a mix of visual and hands-on learning."*

Ultimately, this student developed a flow chart which could potentially be considered a procedural visual representation, but is not hands-on. This potentially shows that students are

less aware of their learning preferences than they believe and having them design their own curriculum could enlighten them to the value of learning from multiple different representations [30-31].

What students often mistake as their learning style is in reality just their interest for a subject. When students are interested in what they are learning, they learn better, and potentially perceive delivery method as their preferred learning style [27-28]. Having students design their own curriculum allows them to align it with their interests. The sole BME student demonstrated this by creating an in-class activity where students use moment equilibrium to calculate the tension in their biceps while holding a dumbbell at different angles during a bicep curl. She expressed her desire to create such an activity in the following excerpt from her final interview:

> *"It's hard to relate to trusses and there's little tools in my statics textbook that I don't even know what they are. I'm a biomedical engineer, I'm taking all these general engineering classes and when there's that one example in biomechanics, then I'm all in on that and it makes sense to me."*

While the students' passion for meshing their learning activities or aids to particular learning styles is an interesting finding, future iterations of this project may consider correcting this notion during the first interview and encouraging students to explore ways that can make their chosen statics topic more interesting to them and their peers through multiple different representations.

The authors' favorite part of this project has been the empathy students develop for their instructors and express in their final interview after completing the project. One student discussed how this project made them less judgmental of when their surveying professor had mistakes in their notes:

> *"It definitely takes a lot of time to make a full semester's worth of stuff. Like when I was taking surveying, the professor's notes would have like five corrections. I was starting to get a little fed up with it. It was like every day, repetitively. But thinking about it, their notes were like five or six pages long each day, just tons of stuff. So I can imagine there's mistakes in there, and it's probably hard to proofread that for a whole semester's worth of notes, especially because I think they haven't taught surveying that long. You couldn't proofread that stuff in that amount of time."*

This same student created the method of sections problem that emphasizes the importance of identifying zero force members before making a cut. He drew his problem in AutoCAD and expressed going through several iterations in his final interview:

> "*I didn't realize that there's a lot of trial and error. It kind of feels like there's this perfect question, I guess. You see it in the textbook, it makes sense, but it kind of shows you that there's a lot of behind-the-scenes work that goes into making a question that seems perfect because it probably starts out not perfect. […] I had quite a few iterations because I tend to just go on AutoCAD and print it off and then look at it, and then I usually mark it up with changes I want to do and go back and make those changes."*

These two excerpts show how this student had an initial expectation for his professors and textbooks to have perfect curriculum with little understanding of the iterative process it takes to create near perfect curriculum until he experienced it through the creation of his single problem.

The following two excerpts from different students expressed a similar realization of the iterative process and attention to detail required in developing curriculum:

> *"At first, I thought this would be pretty straight forward. But then as I went further along into developing it, I noticed that there's little issues that pop up every now and then that you have to solve, figure out how to handle that, and even then more issues might happen because you found out that one thing. And then it's a long line of stuff that goes into developing curriculum."*

> *"The amount of attention to detail that the professors have to have to create curriculum is actually very impressive. I went into this, and I didn't think too deep into these types of things. But then after these three interviews, there's a lot of things that the professors have to think about. Is it too much for the students? Is it too little? How can I encourage students to do this assignment so it can help them learn more?"*

Staying on top of iteratively improving curriculum requires a lot of time for instructors. The students increased awareness for this process for a single activity led them to having empathy for how difficult and time consuming it is for instructors to do this for entire courses as illustrated by the following excerpts from two different students:

> *"The amount of time it took just for one topic, I think I understand…yeah, these professors, they got it a little bit hard."*

> *"Developing curriculum for a whole class, I've got a new appreciation for that because I just did one topic, but it's multiple topics throughout the whole semester. I think it's a lot harder than most people think. […] And I feel like just knowing all the information and how to teach everything is a lot more complicated than I would expect and most people would expect."*

While we do not know how much time and effort each student spent in developing their learning activity or aid, based on what the student of the previous quote submitted, he seemingly put in less effort into his deliverable than most his peers. Developing a way to account for the students' effort on this project in their grade while maintaining the creative freedom for students to develop whatever they want is something the authors are exploring for future implementations. However, it was good to see that even the students that seemingly put less effort into this project still developed a deeper appreciation for the challenges of curriculum development and empathy for their instructors. As another student who seemingly put less effort into his deliverable than his peers said in his final interview:

> *"What I really liked about this project is you can use your creativity if you want to and just create your own thing. You get to put yourself in the professor's shoes and just actually try to create your own thing. It was a pretty good project. It wasn't difficult, but*

it wasn't super easy. There's still things I had to think about. If I were to do it again, I'd probably go deeper into it."

Lessons Learned and Future Research

As alluded to at the end of the last section, there was a considerable range in effort that students put into developing their learning activity or aid. Since the students were graded based on participating in all the interviews expected of them and producing a final deliverable by their last interview, all students received full credit for this project in their respective courses. As instructors, this made us uncomfortable that some students who seemingly put in less effort received the same grade as students that dedicated more time and effort into their learning activity or aid. The challenge we have faced in adding an assessment component to the final deliverable is maintaining the students' creative freedom to develop whatever they want for the statics topic of their choosing. Depending on what topics students choose and what they choose to design, there will be inevitable differences in the level of effort required.

Our future research goals are to implement this project in a full semester term of a dynamics or MoM course and eventually develop a framework for how to structure this project for instructors of post-requisite courses wishing to offer their students a similar experience. A critical part of this framework will be assessment strategies for the unique curricular designs that students create. Some additions that we plan to test out in the next implementation are requiring the students to write a proposal for their learning activity or aid with clear final deliverable goals at the beginning of the term and then do an in-class presentation or demonstration of their learning activity or aid at the end of the term. The proposal could be graded in a way that provides students feedback on whether they need to expand or reduce their scope and how to do so while setting clear benchmarks to meet by the middle and end of the term. The presentation can provide another point of assessment while also providing an additional incentive for the students to produce something they are proud to present to their peers. Instructors with larger class sizes could consider making this a group project to keep the amount of projects that need to be graded manageable. Another option for instructors of large classes would be to narrow the options for what types of learning activities or aids their students could develop. For example, and instructor could ask for students to only focus on developing a flow chart for a given topic or set of topics.

Conclusion

The objectives of this study were to provide students with a curriculum design opportunity to improve their understanding of a statics topic, potentially improve our statics curriculum, and increase student empathy for instructors and the challenges of curriculum design. Students often have little to no say in the curriculum they receive, which can limit their sense of agency in their education and their understanding of their instructors' curricular decisions while fostering an adversarial relationship towards their instructors [4]. By providing a project in post-requisite statics courses for students to develop curriculum, they can improve their understanding on a statics topic of their choosing, potentially help future statics students, and develop empathy for their instructors. Two of the learning activities developed by the

students that participated in this project are being adopted into our statics curriculum and all of the students expressed a newly found appreciation for the challenges instructors face when designing curriculum. Such opportunities have not typically been offered to students because of their lack of expertise in curriculum design. Certainly students do lack this expertise; however as recipients of curriculum, they have valuable opinions on what they want from curriculum. For some students, this can motivate them to develop worthwhile learning activities or aids when given the opportunity. While we are happy that this research has led to some new curriculum for our statics courses, we are even more pleased with the effect this project has had on our students' appreciation for the time and effort their instructors dedicate to developing curriculum.

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