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Can Hands-on Statics Improve Student Learning?

Prof. Eric Davishahl, Whatcom Community College

Eric Davishahl serves as professor and engineering program coordinator at Whatcom Community College in northwest Washington state. His current project involves developing and piloting an integrated multidisciplinary learning community for first-year engineering. More general teaching and research interests include designing, implementing and assessing activities for first-year engineering, engineering mechanics, and scientific computing. Eric has been an active member of ASEE since 2001. He was the recipient of the 2008 Pacific Northwest Section Outstanding Teaching Award and currently serves on the ASEE Board of Directors as Zone IV Chair.

Dr. John Chen P.E., California Polytechnic State University, San Luis Obispo

John Chen is a professor of mechanical engineering. His interests in engineering education include conceptual learning, conceptual change, student autonomy and motivation, lifelong learning skills and behaviors, and non-cognitive factors that lead to stu

Alan Zhang, California Polytechnic State University, San Luis Obispo
Dr. Kathryn Mary Rupe, Western Washington University

Kathryn Rupe is an assistant professor of math education at Western Washington University. Previously, she taught middle school math and worked as an instructional coach in Chicago Public Schools for 10 years.

Does Hands-On Statics Improve Student Learning?

Abstract

Mechanics instructors frequently employ hands-on demonstrations and activities in hopes of improving student learning outcomes. This paper presents results from a study exploring the effectiveness of a hands-on statics curriculum that spans several topics and is designed for implementation over multiple weeks. The modeling kit and associated series of activities integrates conceptual exploration with analysis procedure tutorials and aims to scaffold students' development of representational competence, their ability to use multiple representations of a concept as appropriate for learning, problem solving, and communication.

We conducted this study over multiple sections of a statics course taught by two faculty at a mid-size public university. Both instructors taught intervention sections in fall 2023 using the modeling kit for the first time. One of these instructors taught two more intervention sections in winter 2024. They both administered a test of 3D vector concepts and representations called the Test of Representational Competence with Vectors (TRCV) in weeks 1 and at mid-term, the Mental Cutting Test (MCT) for spatial abilities in weeks 1 and at end-of-term (nine weeks later), and the Concept Assessment Test in Statics (CATS) at end of term. Control sections were taught by the same two instructors in fall 2022. These sections administered the same assessments on the same schedule but did not use the hands-on curriculum.

We compare learning outcomes between the control and intervention sections as measured by the scores on the assessments described above as well as final course grades. Larger pre/post gains on the TRCV across all intervention sections is evidence that the modeling kit produced improved learning gains with respect to vector concepts and representations. We also share reflections from the two faculty participants regarding their experiences teaching with the models. Overall, the instructors' experiences and reflections demonstrate the importance of adapting an outside curriculum to the specific educational context in which it will be implemented.

Introduction

There is a consistent strain of reporting on the use of hands-on models and manipulatives in statics instruction dating back decades [1]- [7]. Purported benefits of using models in the classroom include demonstrating physical phenomena, aiding visualization, addressing misconceptions, exposing students to "real-world" problems, and promoting an engaging classroom environment. This paper focuses on a study using a hands-on statics curriculum focused on promoting conceptual understanding, supporting students' developing spatial abilities, and engaging them in active learning. We have described our approach extensively in prior work [8], [9] and have made the models and associated example worksheets available at https://staticsmodelingkit.wordpress.com/. To summarize, the curriculum targets conceptual knowledge along with complementary analysis skills embedded within a problem-solving context in guided activity worksheets. The worksheets prompt application of multiple representations (e.g. diagrams, symbolic math, and graphs) and representation translations as students work with the models to complete problem-solving oriented tasks. Through this process, students work with each other and with the instructor to resolve misconceptions (or naïve conceptions) and build mental models of the underlying meaning the representations communicate [10]. Understanding what each representation means and how to apply it effectively in problem solving is important to students' development of both conceptual and procedural knowledge in mechanics. The construct of representational competence (aka representational fluency) embodies this skill, and is commonly used in the science education literature and is seen as a marker of domain expertise [11], [12], [13].

We described in prior work how the model-based curriculum received positive student feedback when implemented in a flipped classroom taught by the primary developer of the curriculum [8], [9]. We also saw moderately improved learning gains and generally positive feedback using an adapted take-home version of the models in the remote learning modality in the context of the COVID-19 pandemic [14]. Students consistently reported the activities were useful for developing their understanding of concepts such as 3D vector operations, moments, and support reactions [8], [9]. For the current study, two statics instructors implemented the models in fall 2023 and winter 2024 and collected assessment data for comparison to data from the same assessments administered in control sections taught by the same faculty in fall 2022 without the models.

Study Design

There were significant differences in the background of the two faculty participants that led to substantial variation in how they incorporated the models into their teaching. The fall 2022 control section marked the first time one faculty participant (referred to as Instructor A for the remainder of this paper) had ever taught Statics and their first term of full-time college teaching. They were still developing their teaching approach as of fall 2023 and adopted most of the provided curriculum into the early weeks of their intervention section, implementing the provided worksheets with minimal modifications for the topics that aligned with their course outcomes. Work with the models constituted a significant fraction of classroom time for the first third of the quarter, implementing four activities in the first three weeks. Instructor A made some adjustments later in the term in response to student feedback regarding the amount of class time devoted to activities, ultimately implementing two activities (out of three originally planned) over the middle five weeks of the term.

Instructor A taught with the models again in winter 2024 but made substantial modifications to how they used the models in response to student feedback from fall 2023 and to align more with their teaching approach in general. While they planned to have the same total number of activities, they adjusted the scope of each worksheet to be more manageable in the class time and emphasized holding a group discussion on the concept questions at the end. They also provided additional reference photos of completed models and numerical answers for students to use as checkpoints for understanding during the class period. This allowed groups to evaluate the accuracy of their work and proceed through with less bottlenecks waiting for instructor feedback.

The other instructor (Instructor B) came to this project with much more prior experience with Statics and with teaching in general. Fall 2023 was their tenth year teaching this course out of the past 13 years. They have a well-established approach to teaching statics that is generally well-received by students, so they were more conservative in how they incorporated the models. Upon reviewing the curriculum, Instructor B perceived the models as being primarily useful for helping students learn 3D equilibrium problems and therefore only used the provided curriculum for this topic. He further created an additional 3D equilibrium example as well as a problem more focused specifically on representing 3D Cartesian vectors. Finally, Instructor B used the manipulatives to demonstrate support reactions. This work occurred during the middle weeks of the term as students were preparing for the first midterm exam.

We used the following assessments to compare learning outcomes between the control (fall 2022) and intervention (fall 2023, and winter 2024) sections for both instructors.

- Pre (week 1) and post (week 10) Mental Cutting Test for spatial abilities [15].
- Pre (week 1) and post (week 6) Test of Representational Competence with Vectors (TRCV) [16], [17].
- End of term (week 10) Concept Assessment Test in Statics (CATS, formerly known as the Statics Concept Inventory) [18].
- Final course grades.

Students were incentivized with minor extra credits for completing the first three assessment types, regardless of the accuracy of their responses.

Study Population and Context

This study took place at a midsize public university on the west coast. The course is taught by the mechanical engineering department and serves several other majors. Integral calculus and one quarter of calculus-based physics (mechanics) are both required prerequisites. Table 1 below summarizes the study population with sample sizes and student-reported prerequisite course grades. We tested the differences in mean prerequisite grades for statistical significance using two-tailed t-test between the control and intervention sections for each instructor and found that the winter 2024 students' prerequisite grades are significantly lower for both math ($p<.05$) and physics ($p<.01$) compared to Instructor A's fall 2022 control section. The overall number of students in the study is too low for demographic breakdowns to be meaningful.

Table 1. Study population.

Term	Enrollment (last week of term)	Number Consenting to Study	Mean MATH prereq grade	Mean PHYS prereq grade
Fall 2022 Control				
-Instructor A (2 sections)	63	35	3.48	3.13
-Instructor B (2 sections)	71	62	3.19	3.33
Fall 2023 Intervention with Models				
-Instructor A (1 section)	30	29	3.27	3.11
-Instructor B (2 sections)	71	46	3.43	3.08
Winter 2024 Intervention with Models				
-Instructor A (2 sections)	70	61	3.04^{**}	2.78^{*}

*Significant at $p<.05$, ** Significant at $p<.01$ (two-tailed t-test)

All sections were taught on a 10-week quarter calendar with three 50-minute class meetings per week. Section enrollments were capped at ~35 students. In the intervention sections, modeling kits were provided such that instructors could run group activities with a minimum of one model per three students.

Results and Analysis

Mental Cutting Test (MCT) Results

The MCT assesses spatial abilities by asking learners to visualize the 2D projection of an inclined section cut of a 3D object [15]. We administer this test during week 1 based on earlier findings with a different study population that students' TRCV posttest scores had a significant correlation to their MCT pretest scores [17]. We also hypothesize that students may be able to gain some spatial skills training by working through the modeling kit activities. Table 2 presents the MCT results for the current study population after filtering for consenting students who completed both the pre and post assessments.

Table 2. Mental Cutting Test (MCT) scores (25 points possible).

Course Section	N	MCTpre		MCTpost		MCT gain
		Mean	St. Dev.	Mean	St. Dev.	
F22 A (control)	35	15.1	4.9	15.8	5.4	0.7
F23 A (models)	28	16.4	5.7	17.0	5.0	0.6
W24 A (models)	59	13.4	5.1	14.2	5.4	0.8^{*}
F22 B (control)	60	15.9	4.6	16.3	4.7	0.4
F23 B (models)	42	14.2	4.3	15.0	4.5	0.8^{**}

*Significant at $p<.05$, ** Significant at $p<.01$ (one-tailed paired t-test)

The only significant differences in the gain results are the pre/post gains for F23 Instructor B and W24 Instructor A. While this result is significant, the gain is much smaller than reported in [19] and indicates a small effect (Cohen's d ~ .2) of the students' learning experiences on increasing their MCT score. This result provides little evidence to support the idea that students are using the models to improve their spatial skills any more than in any other statics course. There is also a significant difference between the MCT pretest scores for Instructor A's F23 and W24 intervention sections ($p < .05$). This is further evidence along with the prerequisite grade results in Table 1 that the W24 students entered the course with significantly lower preparation compared to the four other sections in the study. None of the other differences in MCT scores are statistically meaningful, either between sections, or from pretest to posttest within sections.

Test of Representational Competence with Vectors (TRCV) Results

The TRCV measures students' representational competence with vectors in both 2D and 3D applications by using multiple representations in a variety of conceptual analysis problems. Table 3 on the next page presents the results after filtering the study population for students who completed both the pre and post assessments.

Here we see some apparently significant differences between pretest and posttest and between control and intervention sections. Interpreting the results for effect size (Cohen's d) we see that in the control sections, instruction had a small effect (d~.2-.3) on increasing TRCV scores while the models seem to have increased the effect size to medium ranges (d~.5-.6) for both instructors [20] [21]. We follow the guidance in [22] to compute an effect size of introducing the models as:

$$d = \frac{(\bar{x}_{post} - \bar{x}_{pre})_{intervention} - (\bar{x}_{post} - \bar{x}_{pre})_{control}}{s_{pre}},$$

where $\bar{x}$ represents the mean TRCV scores for posttest and pretest and s_{pre} is the pooled standard deviation of the pretest scores, and compute d = .36 (small to medium effect) for Instructor A in F23, d = .22 (small effect) for Instructor A in W24, and d = .24 (small effect) for Instructor B in F23.

Table 3. Test of Representational Competence with Vectors (TRCV) scores (percent correct).

Course Section	N	TRCVpre Mean	TRCVpre St. Dev.	TRCVpost Mean	TRCVpost St. Dev.	TRCV gain	Cohen's d
F22 A (control)	33	48.3%	17.5%	53.6%	16.7%	5.3%*	.31
F23 A (models)	22	50.8%	17.4%	62.5%	17.7%	11.7%***	.66
W24 A (models)	53	44.5%	16.2%	53.4%	17.3%	8.9%***	.53
F22 B (control)	51	47.8%	17.5%	51.7%	19.2%	3.9%*	.21
F23 B (models)	42	42.9%	19.6%	51.2%	17.4%	8.3%**	.45

*Significant at $p<.05$, ** Significant at $p<.01$, *** Significant at $p<.001$ (one-tailed paired t-test)

Course Preparation, Spatial Skills and TRCV Scores

It is possible that some of this difference in the intervention section TRCV results is related to differences in course preparation as indicated by prerequisite course grades and MCT pretest scores. We tested for correlations of TRCV posttest scores against both prerequisite math grades and prerequisite physics grades and found no relationship, but there is generally a significant correlation of TRCV posttest scores with MCT pretest as shown in Table 4.

Table 4. Correlation between MCT pretest scores and TRCV posttest.

Course Section	MCT Pretest Mean	TRCV Posttest Mean	Correl Coefficient Pearson R
F22 A (control)	15.1	53.6%	0.49
F23 A (models)	16.4	62.5%	0.62
W24 A (models)	13.4	53.4%	0.36
F22 B (control)	15.9	51.7%	0.55
F23 B (models)	14.2	51.2%	0.60

Note that the correlation coefficient (Pearson R) varies from 0.36 to 0.62, which is consistent with the correlation coefficient of R = 0.45 that we found in [17] for these assessments. There is one significant difference in MCT pretest scores shown above in Table 2: the MCT pretest mean was 16.4 for Instructor A in F23 compared to 13.4 in W24. We note that the F23 students appear to have made slightly larger gains on TRCV with the highest posttest mean score (62.5%) in the study, further supporting the idea that spatial abilities are helpful for developing representational competence with vectors.

Concept Assessment Test in Statics (CATS) results
We only administered the CATS at the end of the course (no pretest) to avoid assessment fatigue during the first week and consistent with suggestions that pretest scores differ little from random guessing [23]. Table 4 summarizes CATS results. Reported effect sizes compare the CATS scores in the intervention sections to each instructor's respective control section. We also computed the correlation coefficient between the CATS scores and TRCV posttest scores to compare with the correlation of 0.58 that we found in [17], where we concluded that the impact of spatial skills preparation on students' developing understanding of conceptual knowledge is mediated by their representational competence with vectors – the "language" we frequently use to develop mechanics concepts.

Table 5. Concept Assessment Test in Statics (CATS) scores.

Course Section	N	CATS Mean	St. Dev.	Cohen's d	R (TRCVpost)
F22 A (control)	32	36.5%	17.5%	N/A	0.49
F23 A (models)	25	44.9%	24.6%	.40	0.41
W24 A (models)	55	37.8%	16.1%	.08	0.37
F22 B (control)	59	44.6%	21.0%	N/A	0.63
F23 B (models)	43	42.7%	19.5	-0.09	0.65

While the CATS scores for Instructor B were slightly lower for the F23 intervention (negligible effect size and not statistically significant), the CATS scores for Instructor A in F23 increased with effect size d = 0.40 indicating a small to medium effect. For W24, Instructor A's students scored about the same on the CATS compared to the F22 control section, even though these students entered the course less prepared. It seems plausible that the increased TRCV gains apparent in Instructor A's intervention section may have contributed to the improved CATS result. However, we hesitate to lean too heavily into this conclusion because of the negligible effect in Instructor B's CATS data and since this comparison involved two separate, relatively small samples. We also note that the CATS assessment consists exclusively of 2D systems, so any causal relationship between this curriculum intervention focused on 3D visualization and vector concepts and improved CATS scores would be indirect. Furthermore, it's likely that Instructor A improved at teaching statics concepts as they gained more experience with the course in general.

Final Grades
Table 6 on the next page shows our final comparison metric of course grades. Again, we see a substantial effect size (d = 0.36) in increased grades for Instructor A but negligible effect for Instructor B. As stated previously, this difference could be partially explained by increased use of the models by Instructor A but could also be attributed to them having more experience teaching the course in general as of fall 2023.

We note that fall 22 was Instructor A's first experience teaching Statics, so there may be several differences in their teaching emphasis, approach, and even grading practices contributing to the significant increase in fall 23 grades for similarly prepared students. We observe the relatively low grades in the winter 24 section is consistent with those students' significantly lower prerequisite course grades coming into the course. It is possible that the activities with the models helped Instructor A create an active and engaged classroom more supportive of student motivation and learning in general, but it seems like a stretch to connect that to the differences in course grade outcomes. Student feedback data in the next section indicates the activities were generally well-received, however.

Table 6. Comparison of final course grades (4-point scale).

Course Section	N	Numeric Grade	St. Dev.	Cohen's d
F22 A (control)	35	2.89	0.88	N/A
F23 A (models)	29	3.18	0.72	.36
W24 A (models)	61	2.37	0.97	-.53
F22 B (control)	62	3.28	0.88	N/A
F23 B (models)	46	3.34	0.68	.08

Results Analysis Summary
In summary, we conclude the following in comparing assessment results between the control and intervention sections.

- There is little evidence that students develop their spatial abilities (as measured by the MCT) to a greater extent in the context of using the hands-on modeling kit curriculum.
- Increased pre/post gains on the TRCV provide evidence that the models improve student learning of vector concepts and representations. Gains were notably higher in all intervention sections.
- The results show strong correlations between MCT pretest and TRCV posttest and between TRCV posttest and CATS. This finding supports our conclusion in [17] that teaching strategies focused on developing students' understanding of 3D vector representations can also support their understating of statics concepts more broadly, even.
- Final grade results indicate a significant impact of introducing the models into Instructor A's intervention section, but it is difficult to disentangle the effect of the intervention from other possible changes and the evolution of their teaching over the course of their first years in teaching Statics.

Student Feedback

We intended to administer two feedback surveys over the course of the intervention. The first survey seeks feedback on the modeling kit activities focused on 3D vectors and moments. The second survey seeks feedback on activities focused on 2D and 3D rigid bodies in equilibrium. There was some confusion on the part of participants that led to some differences in the timing of survey administration. Instructor A administered the surveys as intended, but Instructor B did so after they were done using the models with the focus on 3D rigid body equilibrium. Instructor B did not administer the second survey since he did not use the models significantly for 2D equilibrium topics. Table 7 on the next page includes the survey prompts and mean student response data comparing results for Instructor A and Instructor B for the fall 2023 intervention sections. The survey uses a 6-point Likert scale with 1 = Completely Disagree, 2 = Somewhat Disagree, 3 = Slightly Disagree, 4 = Slightly Agree, 5 = Somewhat Agree, and 6 = Strongly

Agree. Reported p-values use a two-tailed heterostatic t-test when comparing results between instructors and a two-tailed paired t-test when comparing results from the two surveys for Instructor A.

Table 7. Survey response means for control and F23 intervention (with models) sections.

Survey Prompt	Inst. B Vectors N = 38	Inst. A Vectors N = 25	Inst. A Equilibrium N = 29
1. The models helped me communicate with my classmates.	5.26	4.68	5.14*
2. The activities helped me clarify the material we are learning.	5.45***	3.84	4.52**
3. [Vectors] The models helped me visualize vector concepts (e.g. unit vectors, direction angles, cross product).	5.50**	4.40	N/A
3. [Equilibrium] The models helped me feel the forces and moments in the problems.	N/A	N/A	4.76
4. The activities helped me connect different representations of the concepts (i.e. figures, diagrams, graphs, notation, equations, written descriptions, etc.).	5.13**	4.20	4.59
5. The models helped me visualize and interpret the figures and diagrams on the worksheets.	5.50***	4.36	4.62
6. Working with the models helps me visualize and interpret other figures and diagrams in the reading and problem sets.	5.26**	4.28	4.38
Overall Response Mean	**5.35*** **	**4.29**	**4.67**

*significant at $p < .05$, **significant at $p < .01$, ***significant at $p<.001$, comparisons to adjacent column

The pattern in student feedback is somewhat contradictory to the assessment results presented above. Students had a generally more positive reaction to the activities in the intervention sections taught by Instructor B. This difference was large enough to be statistically significant for all but the first survey prompt. Some explanation for this difference can be found in the narrative comments accompanying the Likert scale questions. Instructor A's students seemed to generally view the activities as helpful for learning concepts. But they questioned the amount of class time devoted to these activities and perceived this focus as coming at the expense of instructor-led examples and practice problems which might be more helpful for completing homework. Consider the following example comments that illustrate this theme:

- *I do come away from the learning activities with a better understanding of statics concepts, however I wonder if the activities could take slightly less time. I worry that I am losing in class concept time while focusing on concepts I mostly understand.*
- *I think the activities are helpful on occasion, but not effective in learning the bulk of the material. They are useful for visualizing the big concepts, but I think time would be better spent going through example problems and getting repetition setting up and solving the systems of equations that will be crucial for overall learning and exams.*
- *I like the idea of the modeling kits. One issue is I feel like we spend a lot of time on them and then lose out on lecture time. I feel like it is inefficient learning, I begin to understand the concepts, but I feel like it takes too long using the modeling kits. I would prefer doing more practice problems and lectures and do the modeling kits like every other week. Or not spend the whole class on them.*

Two themes that emerge from these and other comments in the survey are (1) a perceived mismatch between class time emphasis and what students are asked to do on homework and exams and (2) perhaps some student resistance to active learning (and the class time involved) in general. We also note that Instructor A started the intervention by using the provided activity worksheets with minimal modifications, but the Statics course at the institution where the worksheet activities were developed has two additional hours of class time per week.

In contrast, the narrative comments from Instructor B's students reflect that instructor's approach of focusing on using the modeling kits primarily to reinforce what they were already doing with respect to 3D rigid body equilibrium. Students seemed to perceive the modeling kit activities as better connected to the other things they were being asked to do in homework and exams.

- *I am a visual/tactile learner so having images in the slides and a 3D model that was tangible was really cool to have in class and helpful when understanding the reaction forces/moments acting on the body.*
- *The models really helped me grasp the concept of reaction forces and moments. Being able to see the body physically and interact with it helped with understanding the degrees of freedom that connections (hinges, ball and socket joints, leaning against walls, etc.) allowed on the bodies.*
- *This activity really helped me generally understand reaction moments.*

Instructor A did pivot at mid quarter in response to feedback and devote more class time to lecture and examples. This perceived change may in part explain the improved student feedback on the second survey, though less activities were planned for the second half of the term from the start. We separately present the feedback results for Instructor A's winter 24 section below in Table 8 because they made significant changes to how they incorporated the models.

Table 8. Survey response means for W24 intervention section with comparisons to F23 A.

Survey Prompt	Inst. A Vectors W24 N = 56	Inst. A Equilibrium W24 N = 59
1. The models helped me communicate with my classmates.	5.30*	5.42
2. The activities helped me clarify the material we are learning.	4.84**	5.10*
3. [Vectors] The models helped me visualize vector concepts (e.g. unit vectors, direction angles, cross product).	5.20*	N/A
3. [Equilibrium] The models helped me feel the forces and moments in the problems.	N/A	5.08
4. The activities helped me connect different representations of the concepts (i.e. figures, diagrams, graphs, notation, equations, written descriptions, etc.).	4.82	5.24**
5. The models helped me visualize and interpret the figures and diagrams on the worksheets.	5.18*	5.41**
6. Working with the models helps me visualize and interpret other figures and diagrams in the reading and problem sets.	5.07*	5.29***
Overall Response Mean	**5.07*** **	**5.26*** **

*significant at $p < .05$, **significant at $p < .01$, ***significant at $p<.001$, comparisons to F23 feedback

The changes that Instructor A made to their approach were clearly well received by the students, with statistically meaningful improvement for nearly every feedback prompt. This improvement is supported further by several student comments:

- *They just make it easier to visualize what is happening in a problem. This prevents me from confusing myself while trying to figure out the logistics of a problem.*
- *Overall, the modeling activities are very beneficial for me because I am a big visual learner. It also helps me break out of my shell and engage with my classmates.*
- *The modeling kits are actually pretty fun and they help provide a different perspective into the concepts that isn't just equations on a paper.*

Instructor Participant Reflections

This section presents reflections written by the two participating instructors based on their experience teaching with the modeling kits.

Instructor A
I have had an overall positive experience using these models. Many engineering students struggle with 3D visualization skills, and I believe that this kit effectively demonstrates Statics principles to students in a tangible and intuitive manner. The worksheets have practice problems built into them and do not detract from lecture time nearly as much as it seems from first glance.

I attribute my increased final grades for my first intervention section to a combination of factors: 1) a relatively strong class that overall did not struggle too hard with Statics concepts; 2) the overall improvements I have made in my personal teaching style. In my opinion, the modeling kits synergized with my teaching style to engage students and motivate their learning. Rather than just improving their vector competency, I believe the kits worked within the class structure itself to promote long-term student learning and retention of Statics concepts.

For my second quarter using the kits, I made more substantial modifications to the worksheets now that I better understand the scope of what students can finish within a 50-minute class period. The numerical answers to the worksheet example problems served as a good checkpoint for students. Students could quickly and independently troubleshoot their own work to continue their learning, in case I was preoccupied with helping another group. I also purposefully built in time to discuss the conceptual questions at the end of class and then provided targeted feedback when reviewing the worksheets rather than just checking for participation. I believe that these practices motivated my students by tasking them with realistic and achievable amounts of work, and by emphasizing to them that I care about their learning progress.

Overall, I am very impressed with the kits' impact on student learning. In the future I look forward to exploring new worksheets and integrating similar concept questions into other class assignments to further strengthen mental visualization of statics concepts.

Instructor B
Upon receiving the models and reviewing the curriculum, I immediately saw their power in helping some students with the challenging concepts within 3D equilibrium. While I believe I do

a reasonable job in helping my students visualize these problems while restricted to a 2D space, I also suspect that a small minority of students may have difficulty with this. This difficulty with creating and holding a mental model of the problem, I reasoned, may be just enough to impose a cognitive drain on these students as they try to then apply new and unfamiliar concepts to solving 3D problems (e.g., determining appropriate support reactions, calculating moments about a point, etc.). I hypothesized that reducing the cognitive load of "seeing" a model of a 3D problem would then allow the students to focus more on solving it.

In reflecting on the differences in how I taught the control (F22) and intervention (F23) sections (which is nearly none with the exception of the incorporation of the models), I believe that the significant gains measured in the TRCV scores were likely due to the use of the models.

Conclusions

This study adds to evidence in the literature that active learning with hands-on models can improve student learning of mechanics concepts. Improvements in student scores on the TCRV seemed to correlate to how intensively the two participating instructors implemented the modeling kit curriculum in the early weeks of the course. Usage of the models likely played a role in substantial year-over-year improvements in course outcomes for Instructor A. Overall, the instructors' experiences and reflections demonstrate the importance of adapting an outside curriculum to the specific educational context in which it will be implemented. Further improvements in learning outcomes are likely possible for both participants as they continue to adapt the hands-on curriculum to their institutional context and respective teaching approaches.

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