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WIP: Hands-On Statics in the Online "Classroom"

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Abstract

Engineering instructors often use physical manipulatives such as foam beams, rolling cylinders, and large representations of axis systems to demonstrate mechanics concepts and help students visualize systems. Additional benefits are possible when manipulatives are in the hands of individual students or small teams of students who can explore concepts at their own pace and focus on their specific points of confusion.

Online learning modalities require new strategies to promote spatial visualization and kinesthetic learning. Potential solutions include creating videos of the activities, using CAD models to demonstrate the principles, programming computer simulations, and providing hands-on manipulatives to students for at-home use. This Work-in-Progress paper discusses our experiences with this last strategy in statics courses two western community colleges and a western four-year university where we supplied students with their own hands-on kits.

We have previously reported on the successful implementation of a hands-on statics kit consisting of 3D printed components and standard hardware. The kit was originally designed for use by teams of students during class to engage with topics such as vectors, moments, and rigid body equilibrium. With the onset of the COVID-19 pandemic and shift to online instruction, the first author developed a scaled down version of the kit for at-home use by individual students and modified the associated activity worksheets accordingly. For the community college courses, local students picked up their models at the campus bookstore. We also shipped some of the kits to students who were unable to come to campus, including some in other countries. Due to problems with printing and availability of materials, only 18 kits were available for the class of 34 students at the university implementation. Due to this circumstance, students were placed in teams and asked to work together virtually, one student showing the kit to the other student as they worked through the worksheet prompts. One community college instructor took this approach as well for a limited number of international students who did not receive their kits in a timely manner due to shipping problems.

Two instructors assigned the hands-on kits as asynchronous learning activities in their respective online courses, with limited guidance on their use. The third used the kits primarily in synchronous online class meetings. We found that students' reaction to the models varied by pilot site and presume that implementation differences contributed to this variation. In all cases, student feedback was less positive than it has been for face-to-face courses that used the models from which the take home kit was adapted. Our main conclusion is that implementation matters. Doing hands-on learning in an online course requires some fundamental rethinking about how the learning is structured and scaffolded.

Introduction

Engineering instructors frequently employ physical manipulatives and models to help students visualize systems and demonstrate mechanics concepts. Additional benefits are possible through hands-on learning when individual students or small teams of students can engage with concepts at their own pace and focus on their specific points of confusion [1-7]. Online learning modalities require new approaches to promote spatial visualization and kinesthetic learning. Potential solutions include creating videos of activities, using CAD models to demonstrate principles, programming computer simulations, and providing hands-on manipulatives to students for at-home use. This Work-in-Progress paper discusses our experiences with implementation of this last strategy in Statics courses at two western community colleges and a western four-year university where we supplied students with their own hands-on kits.

Take Home Models

We have previously reported on the successful implementation of a hands-on statics kit consisting of 3D printed components and standard hardware [6], [8]. The kit was originally designed for use by teams of students during class time to engage with topics such as vectors, moments, and rigid body equilibrium. With the onset of the COVID-19 pandemic and shift to online instruction, the first author developed a scaled down version of the kit for at-home use by individual students and modified the associated activity worksheets accordingly [9]. Compared to the classroom version design for groups of four students each, the take-home version eliminates several parts and reduces the size of others – reducing the overall raw materials and parts cost from about $140 to $25. Additional substantial savings would be possible by producing parts at scale and moving from 3D printing to plastic injection molding.

In addition to scaling down models to reduce cost, the activities required some rethinking to promote student engagement with the manipulatives as a context for dialog with their peers and instructor. For example, classroom worksheets included prompts for students to use their models as reference to perform basic calculations, to consider relationships between system parameters, and to demonstrate certain concepts for themselves and for the instructor. For the at-home version, we replaced some of these with instructions to submit photos of their model use. Some example student submissions are included below.

Curriculum Implementation

The adapted take-home statics kit curriculum consists of nine worksheet activities listed in Table 1 on the next page. Each activity has two paired multiple-choice concept questions administered through the Concept Warehouse [10]. The questions represent near transfer and far transfer applications of the concepts explored in each worksheet. Students can be prompted to both explain their answers and rate their confidence along with submitting their answer choice. The full suite of modeling activities including STL files for 3D printing, parts lists, references, and activity worksheets for both the classroom and take home versions is available at https://staticsmodelingkit.wordpress.com/. Figures 1 and 2 on the following pages show examples associated with two different activities.

Table 1. Take home statics kit activities.

Activity Title	Main Topics
1.1 3D Vectors	3D Position vectors, vector addition, Cartesian components, spherical direction angles
1.2 Unit and Force Vectors	3D unit vectors, coordinate direction angles
1.3 Dot Product Applications	Angle between vectors, vector decomposition
2.1 3D Concurrent Force System	3D particle equilibrium
3.1 Moments	Moment vectors, scalar and vector approach to computing moments
4.1 2D Rigid Body Equilibrium	Support models, free-body diagrams, rigid body equilibrium
4.2 3D Rigid Body Equilibrium	3D supports, free-body diagrams, 3D equilibrium calculations
5.1 Friction and Impending Motion	Static friction, slipping vs. tipping, friction on a rolling cylinder
6.1 Frame Analysis	Third law force pairs, interacting FBDs, pulleys, frame analysis

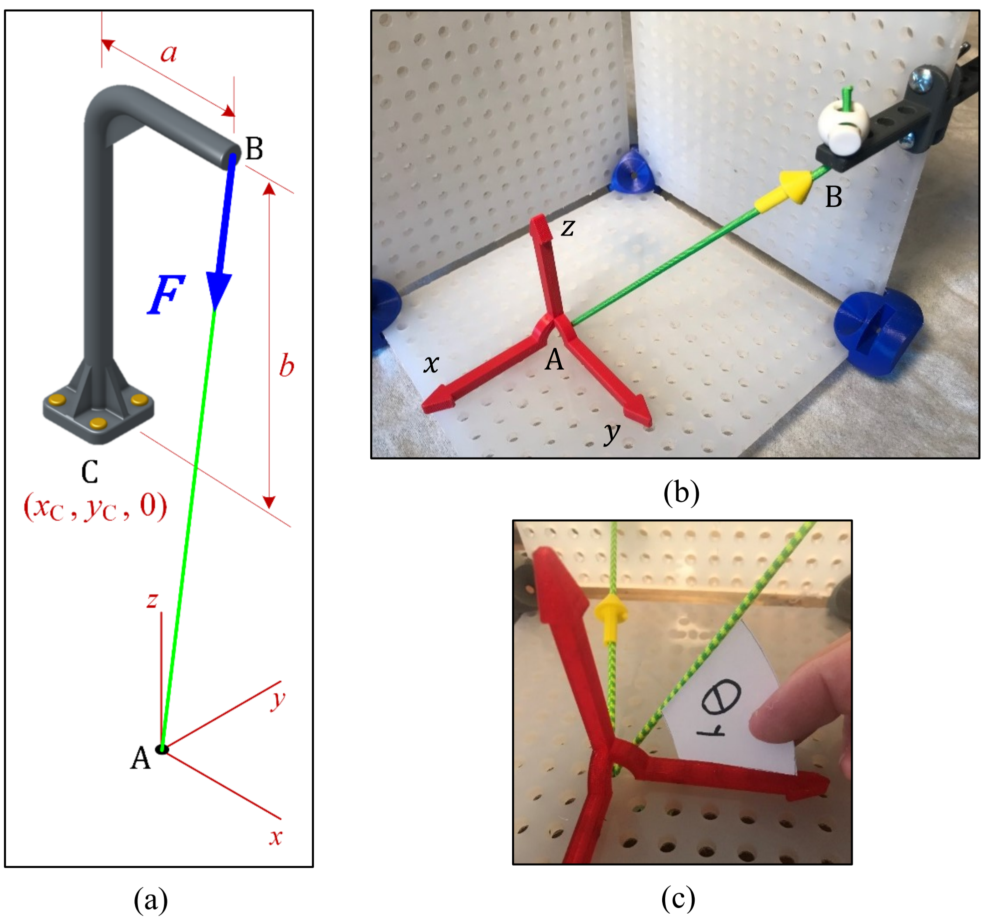
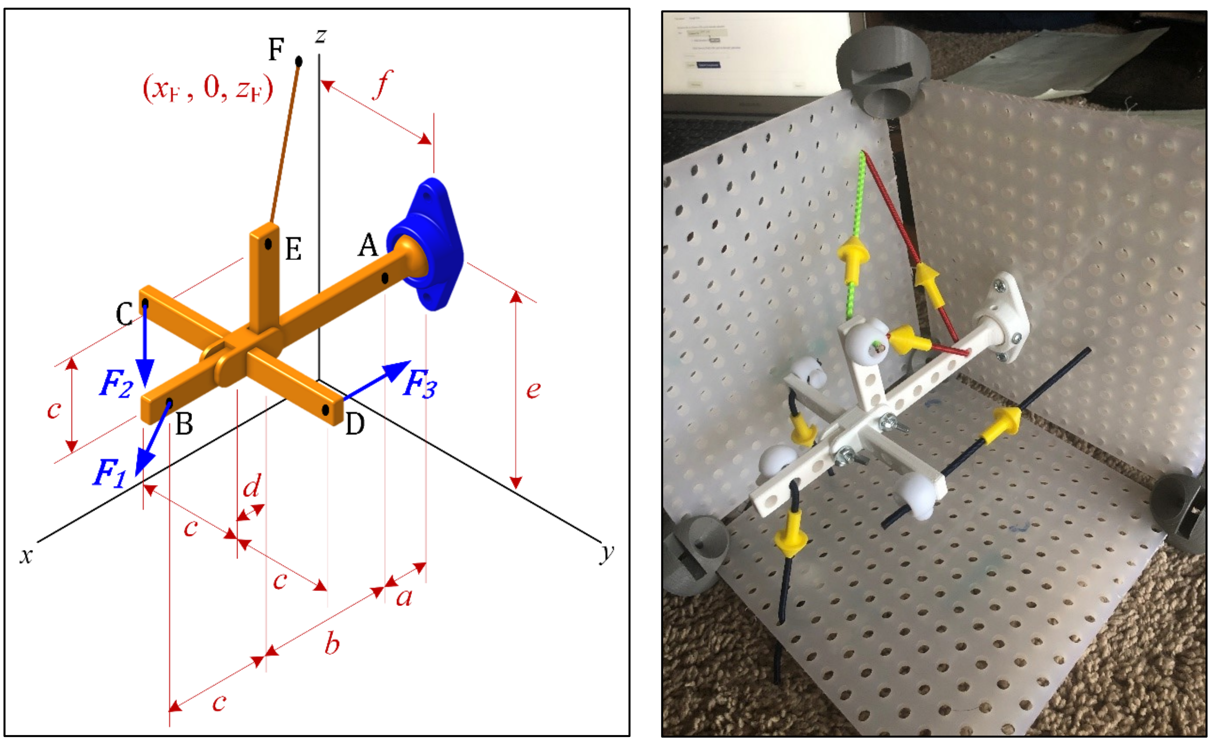


Figure 1. Example vector activity. (a) System diagram. (b) Model. (c) Sample student submission of photo demonstrating their understanding of coordinate direction angles.

Figure 1 is an excerpt from a week 2 activity introducing basic 3D vector concepts and notation. Students perform calculations and answer concept questions related to the system diagram depicted in Figure 1a. Figure 1b shows the model students are instructed to build with their kit to represent the position vector $\boldsymbol{r}_{AB}$ and force vector $\boldsymbol{F}$. Figure 1c is an example student submission demonstrating their understanding of the concept of a 3D coordinate direction angle.

Figure 2 below is an excerpt from an activity introducing 3D moment concepts and computation. Figure 2a shows the system diagram that forms the basis for a series of moment calculations of increasing complexity. The worksheet first guides students through a sequence of calculations using a scalar approach to determine the moments about point A due to $\boldsymbol{F}_1$, $\boldsymbol{F}_2$ and $\boldsymbol{F}_3$ respectively where moment arm and force vectors are orthogonal. In each case, they use a scalar approach to compute the magnitude before determining the direction of the moment vector using the right hand rule. They next move on to a cross product approach. Figure 2b shows an example student submission in response to a prompt to find two possible position vectors (represented by red cords in the photo) that could be used in a cross product to compute the moment about A due to the tension in cord EF (represented by the green cord in the photo).



(a) (b)

Figure 2. (a) Example system diagram for a moment activity and (b) example student photo submission identifying position vectors (red cords) for a cross product computation.

Implementation

Table 2 summarizes the implementation context at the three take-home kit pilot sites: Whatcom Community College (WCC), Cal Poly San Luis Obispo, and Everett Community College (EvCC). The modality column indicates the percentage of course credit hours taught using synchronous web meetings. For example, 40% synchronous would mean two hours per week live web meeting (using Zoom, Microsoft Teams or similar platform) for a five-credit course. All three colleges are on the quarter system with 11-week terms (including finals week) and use the Canvas learning management system.

Table 2. Course terms, enrollment and modalities.

College	Term	Credits	Modality (% synch)	Enrollment
WCC	F20	5	40%	21
Cal Poly	F20	3	67%	34
EvCC	W21	5	100%	30

The two community college statics courses are parts of comprehensive engineering transfer programs that prepare students for university transfer at junior level in multiple engineering majors. Enrollment in these courses consists of students with a diverse array of transfer goals in terms of both specific major and university program. In both cases, these were the only statics course sections offered in the respective terms. Students were likely to know other each other well with established study groups carrying over from prior courses and many commonly worked with each other outside of class without prompting. The university statics course is part of an engineering program including mechanical, aerospace, biomedical, industrial, civil, and general engineering students and was one of 15 sections offered during fall term. Because it is a fairly large polytechnic university, students typically only know a handful of other students within their section.

Distribution Logistics

Distribution logistics varied at the three pilots. At WCC, students picked up their kits at the college bookstore during the first week of class as part of a broader distribution system for a variety of take home kits for science lab classes. This went smoothly with the exception of four international students who were outside of the country. We shipped kits to these students, but they did not arrive until the fourth week of the term. The instructor paired these students with local student volunteers and asked them to work together virtually with one shared kit in the meantime. 24 kits were distributed, but only 17 were returned. The kits that were shipped overseas were not recovered and some kits disappeared with students who withdrew.

The distribution situation at Cal Poly site was quite different. Multiple production hiccups including 3D printing issues and supply shortages led to a delay in having kits ready for the students at the start of the term. Students were finally able to pick up their kits on campus during the second week. These production issues also resulted in there being only 18 kits available for the 34 students enrolled. Due to this circumstance, the instructor placed students in teams and asked them to work together virtually, one student showing the model to the other student as they worked through the worksheet prompts in a similar approach to that used initially for the international students at WCC.

There were also distribution challenges at the second community college site. EvCC used an ad hoc process with the engineering lab technician to distribute models to students on campus. Some miscommunications during the distribution period led to some moderate chaos and student irritation that may have negatively influenced students' initial experience. Nonetheless, all students had models to work with by the second week of class.

Difference in Approaches

There were significant differences in how the hand-on activities were integrated into the three statics courses in this pilot. The instructor at WCC used all nine activities as asynchronous assignments that served roughly as an intermediate point in a weekly schedule that typically started with a reading assignment (includes video options) and introductory problems before moving to the activity worksheet as a step toward a challenging weekly problem set. Students earned full points for effort regardless of the accuracy of their worksheet and were provided an example solution to study. This instructor had been developing the curriculum in the context of face-to-face statics courses for several years. He frequently references the models in other parts of the course such as class discussions and exams and to anchor presentation of certain topics. For example, the WCC instructor implemented the multiple choice concept questions in a pre/post format for each worksheet and frequently used student answer choices and explanations as launching off points for short discussions to clarify concepts during class Zoom sessions that sometimes included repeated use of those same questions with peer instruction. At a minimum, examples of sound reasoning in student written explanations were shared in class notes each week. Exam 1 included a problem that asked students to use their kit to construct their own problem to demonstrate basic vector calculations. This instructor also piloted a new assignment in which students created brief videos using their kit to explain a concept they choose from a brief list.

In contrast, the Cal Poly instructor used seven of the nine activities (all but 1.3 and 6.1) and did not assign the paired concept questions. Activities were assigned as the main portion of the asynchronous portion of the class, and solutions were provided to students after completion. Because this was the first time this instructor had used the kits, he was not as familiar with their use and did not integrate the kits and components much into the rest of the course learning activities. Pre- and post concept testing was not performed.

The instructor at EvCC also used all nine activities and the pre/post concept questions, but weekly implementation was synchronous during one of the class web meetings using Gather.town (https://gather.town). Student groups worked together in breakout rooms to complete the worksheet and then finished any uncompleted sections on their own after class. Students submitted completed worksheets for full credit based on effort only, similar to the approach at WCC. This was the EvCC instructor's first exposure to this modeling curriculum. Inexperience with the kits and the challenge of managing 30 students working with the models in a synchronous online session proved challenging.

Student Feedback

We administered an anonymous survey to collect student impressions of the modeling curriculum at all three sites and found significant differences. Table 3 includes the survey prompts and mean student responses. The survey uses a standard Likert scale with 1 = Strongly Disagree, 2 = Somewhat Disagree, 3 = Neutral, 4 = Somewhat Agree, and 5 = Strongly Agree. Reported p-values use a two-tailed t-test with the WCC results as a baseline for comparison.

Table 3. Survey prompts and response means at all three pilot sites.

Survey Prompt	**WCC N = 16**	**Cal Poly N = 21**	**EvCC N = 19**
The modeling activities helped me…			
1. Understand vector notation and use it properly.	4.13	3.38*	2.95**
2. Interpret figures for 3D problems on homework and exams.	3.94	3.00**	3.10**
3. Visualize vectors in 3D.	4.44	3.52**	3.21**
4. Understand force equilibrium.	4.31	3.14**	3.05**
5. Understand support models.	4.56	3.19**	3.21**
6. Conceptualize moments in 3D systems.	3.88	3.24	3.05*
7. Understand moment equilibrium.	3.88	2.90**	2.95*
8. Develop my free-body diagram skills.	3.44	2.76	3.26
The modeling activities provided…			
9. An effective context for discussing statics concepts with my classmates.	3.56	3.38	2.84
10. Opportunities for the instructor to explain statics concepts in detail.	3.31	3.10	3.05
Overall Response Mean	**3.94**	**3.16****	**3.07****

*significant at $p < 0.05$, **significant at $p < 0.01$, all using 2-tailed t-test comparison with WCC

Students at WCC had a more positive response to the activities in general with statistically significant differences on six of ten items compared to the Cal Poly implementation and on seven of ten items compared to the EvCC implementation. We also note that the student response is less positive than it was for the two most recent terms of face-to-face implementation of the curriculum at WCC. The overall response mean on an identical survey, aggregating results for fall 2019 and spring 2020, was 4.43 (N = 28). This difference with the online implementation at WCC is significant at $p < 0.01$. In summary, the student response to the models as implemented online is generally positive (mean greater than 3) but significantly less so than it has been in face-to-face courses and apparently dependent on the specific implementation practices at each pilot site. This difference may be attributable to the general state of stress and dissatisfaction in students trying to learn during the COVID-19 pandemic. It may also be due to not fully adapting the approach to the online learning environment due to both time constraints and incomplete understanding of what modifications are important.

Conclusions and Recommendations

This work-in-progress paper shares our experience implementing hands-on learning in an online Statics course by sending model kits home to students. We found that students' reaction to the models varied by pilot site and presume that implementation difference contributed to this variation. In all cases, student feedback was less positive than it has been for face-to-face courses that used the models from which the take home kit was adapted.

Our main conclusion is that implementation matters. Implementing hands-on models in this online modality requires some fundamental rethinking about how the learning is structured and scaffolded. Activities designed to create productive struggle in the classroom (with peers and instructor close by to work through confusion) can just lead to struggle and frustration for some students working individually at home.

Based on this experience, we have the following recommendations for continued development of online activities that use take-home models.

- Integrate the modeling activities into other aspects of the course design by referencing them in lectures and other activities and assignments.
- Make videos demonstrating for students how they can use the models to help think about the questions and problems in the worksheet activities.
- Build interactive worksheets that give students immediate feedback if they are on the right track so they do not start on the wrong foot and work the whole activity from a starting mistake or misconception.
- Consider using modeling activities as a basis for sessions with peer learning assistants or other academic support so that students have synchronous help close by as they work through the activities.
- Supplement hands-on activities with virtual simulations that provide alternate modes of interaction with concepts and another way for students to see what they should be seeing with their models.

Online mechanics courses are likely to proliferate in the coming years as the abrupt shifts to online learning amidst the COVID-19 pandemic has prompted many students, faculty, departments, and institutions to revisit beliefs and assumptions about online courses. The authors believe in the potential of hands-on models to support student learning in mechanics and hope this paper will provide an opportunity to learn from our experiences and adapt other hands-on approaches for online implementation.

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