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WIP: A 3D-Printed Frames and Machines Activity in Statics

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A 3D-Printed Frames and Machines Activity in Statics

Abstract

The 3D-Printed Frames and Machines Activity was designed, tested, and finalized in summer of 2022. The activity is designed to resemble a real-life problem to help students gain a deeper understanding of this subject in their Statics class. The activity utilizes parts from a previously made 3D-Printed Statics Modeling Kit, and new parts that were redesigned from the kit to create the activity. The parts were created in SolidWorks and were exported into Ultimaker Cura and printed on an Ender 3 Pro. The activity and students' perception on the activity, which was utilized in fall 2022, is discussed in the current paper.

Introduction

Frames and Machines is one of the most complex topics in a Statics course, due to combining previously learned knowledge from the course and applying it to complex structures with connected members. The previous research on Frames and Machines is limited in the literature. Prins [1] believed that students need to understand different parts in an assembled object, understand where the parts are connected, and how the object moves [1]. He created lab activities using different sizes of bolt cutters and asked students to perform a force analysis. This enabled students to predict and see how different parts of the model work together. Prins found that this is the best method for students to enhance their understanding of a typical machine problem. The researcher reported that following the activities, more than 80% of students were confident in applying their Frames and Machines analysis abilities to real objects [1].

Ramming and Phillips [2] investigated the benefits of having hands-on experiments in their statics class. They incorporated three experiments into the class covering the topics of particle equilibrium, truss structures, and static friction. Students were given a handout for each experiment, consisting of several questions that helped students think through and follow a process in order to solve a problem by drawing free body diagrams (FBD). The handout also offered a section where students could reflect on their results, and make a conclusion on what they did incorrectly. They compared average homework, exam problems, and overall exam grades for semesters that included the lab exercises versus semesters that did not. They found that the homework and exam problem grades of students who had the experiments were higher than students who did not have them. However, when comparing overall exam results there was some discrepancy between whether the experiments were beneficial or not. They believed that the discrepancy in results could be due to not giving the same problems for homework and exams each semester. Overall, they found that hands-on experiments were beneficial to students' understanding, especially for those who do not learn well in a traditional classroom environment [2].

Wodin-Schwartz et al. [3] created experiments that students could remotely model from their homes during the Covid pandemic in 2021. These experiments utilized items that could be found in students' homes or could easily be purchased. In regards to Frames and Machines, students were asked to make two different pulley systems and were asked to determine the loads required to support the weight used. They found that using activities was helpful for students' learning and engagement with the material [3].

With the benefits of hands-on experiments for students, a Statics Activity Kit with six activities was created in Summer 2021 at Ohio Northern University. The activities covered topics on force vectors, dot product, equilibrium of a particle in 2D and 3D, and equilibrium of a rigid body in 2D and 3D. The application of activities in fall 2021 showed that the activities were well received by students and helped them visualize problems and have a better understanding of concepts [4]-[5]. The goal of the current project was: (1) add a new activity on Frames and Machines to be compatible with the previously made Statics Activity Kit and (2) students be able to visually and mathematically understand Frames and Machines. The creation of this project occurred in the summer of 2022. The research into this project began in late May, with prototypes being developed in June.

Product

The developed activity kit in 2021 included a 6.75 in. x 6.75 in. 3D printed table, pulleys with two different sizes of wheels, and beams with hooks and different lengths[4]. Figure 1 shows the pulleys and the beam with hooks. To use the current items in the Activity Kit with minimal modifications, an example from the textbook, as shown in Figure 2, was chosen to guide the creation of the activity [6]. The example also seemed complex enough for students. With the Statics Activity Kit and the example problem, the process of making a final product could begin.

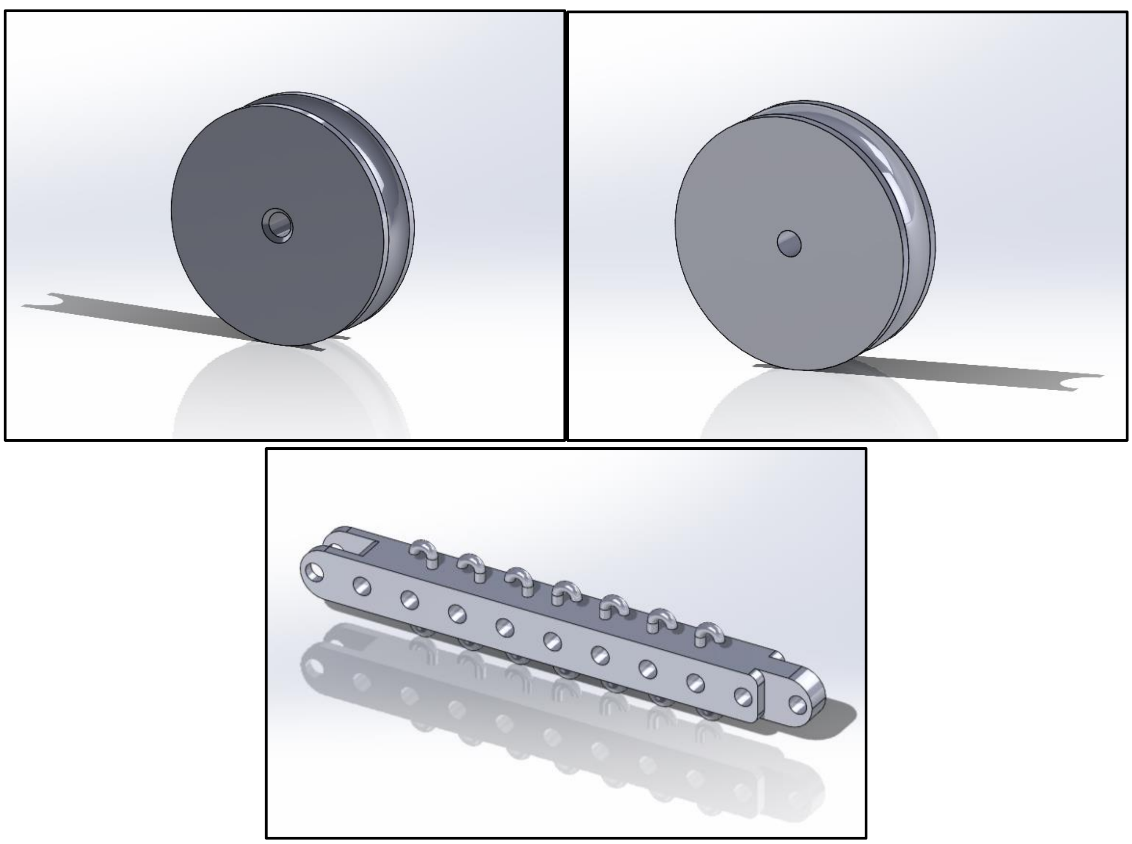

Figure 1: Original Parts

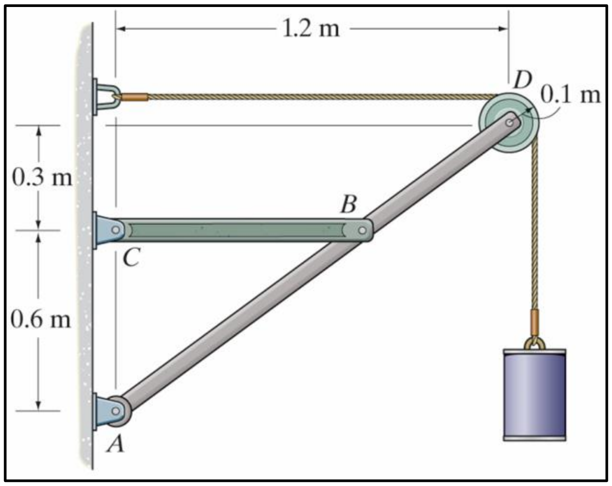

Figure 2: Example Problem from Textbook [5]

Using this example problem, an initial sketch was created to mimic the problem. The sketch can be seen in Figure 3. Member BC was replaced with string and a pulley system was added to support the mass hanging from the pulley.

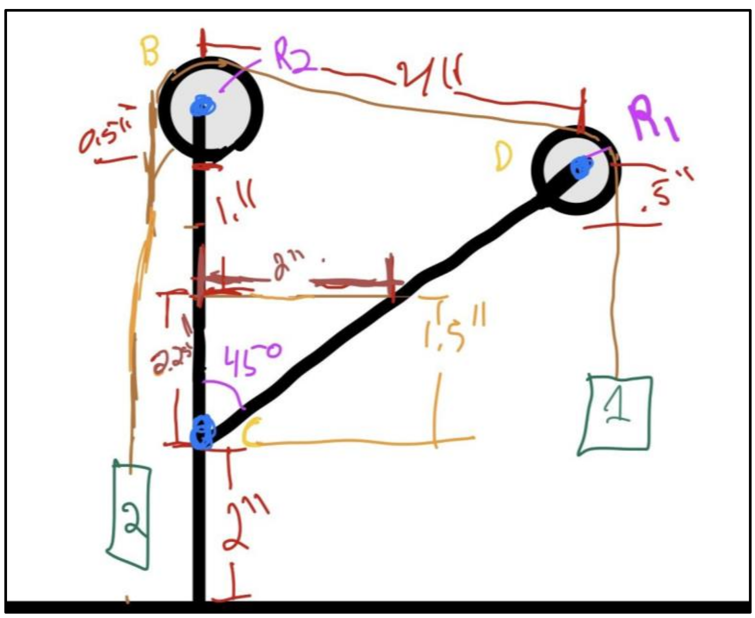

Figure 3: Original Sketch

Initial attempts to create the activity showed that the connection of the string to the vertical peg beam is not secure and the frame is not stable enough. Therefore, a new sketch was made by adding another pulley system in order to support the string and the diagonal member as seen in Figure 4.

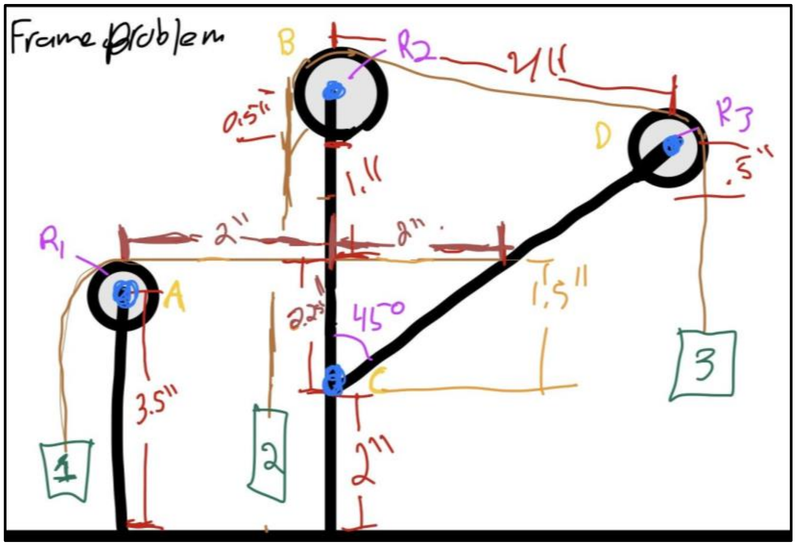

Figure 4: New Sketch with the Additional Pulley System

This addition fixed the stability of the system. This also enables students to compare the calculated force in the string against the mass hanging from it. The original parts in the Statics Activity Kit could not be fully adopted for this activity due to their sizes and designs. Using Solidworks files created for the Statics Activity Kit, the drawings were adjusted so that the parts could fit within the physical model (Figure 5).

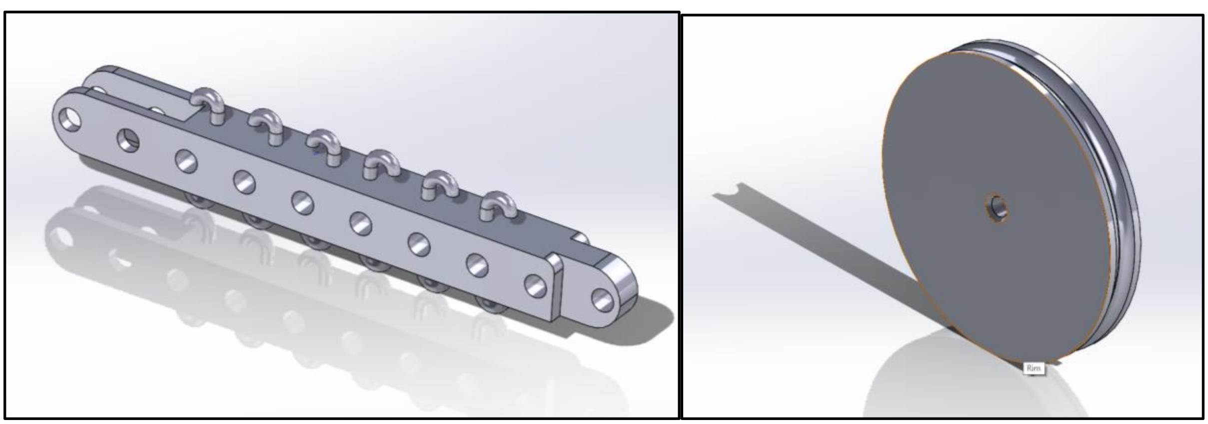

Figure 5: Redesigned Parts

The black wheel originally had a one-inch inner diameter, which was adjusted to a 1.75 inner diameter for this activity. The beam was also redesigned in order to fit the larger diameter wheel. The drawings were then downloaded onto a Cura Ultimaker Ender 3 Pro 3D printer. With the modifications and series of trial and error, the final product was made as shown in Figure 6.

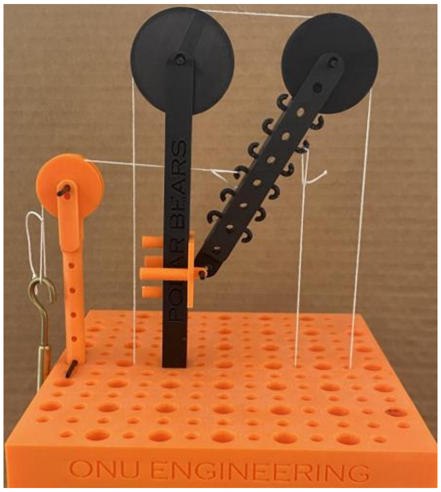

Figure 6: Final Product

Figure 7 shows the assembly of the model with annotations. Students were asked to determine the tension in string BD and support reactions at C. The students were guided to first draw the FBD for the pulley at A and member AC to gain a better understanding of forces between connected members.

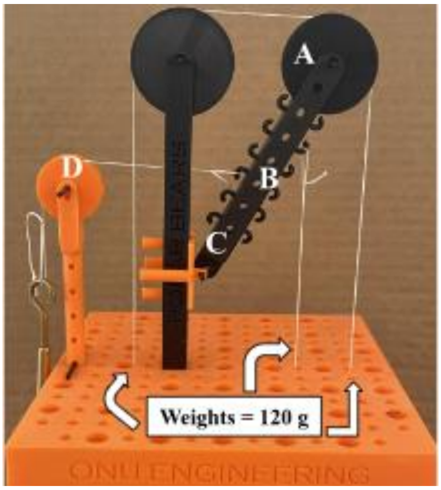

Figure 7: Final Product with Annotations

The problem and the step-by-step procedure are as follows:

Objective: Determine the tension in string BD and support reactions at C. The weight of the member AC is 9.25 grams.

Draw the FBD of pulley A and member AC.

Find the tension force at B.

Tension in BD: _________________(g)

Look at the weight hanging from point D to check your answer.

Actual tension in BD: ____________ (g)

Find the support reactions at C.

Calculated support reaction Cx: __________(g)
Calculated support reaction Cy: __________ (g)

Results

The Frames and Machines Activity was added to the existing activities in the 2022 fall semester. The course consisted of five sections. The instructors took the students to the lab at the end of the class period, explained the setup, and answered students' questions. The students then worked in a group of three to four members to complete the activity. A survey was given at the end of the semester to receive feedback from students. The given statements were: "The activity helped me understand Frames and Machines", "The activity helped me understand how to deal with connected members", "The activity helped me understand the free-body diagram", and "The activity helped me prepare for the exam". Students had to choose from "Strongly Disagree" to "Strongly Agree" for each survey statement. 53 out of 131 students participated in the survey. Figure 8 shows the combined response for all four survey questions.

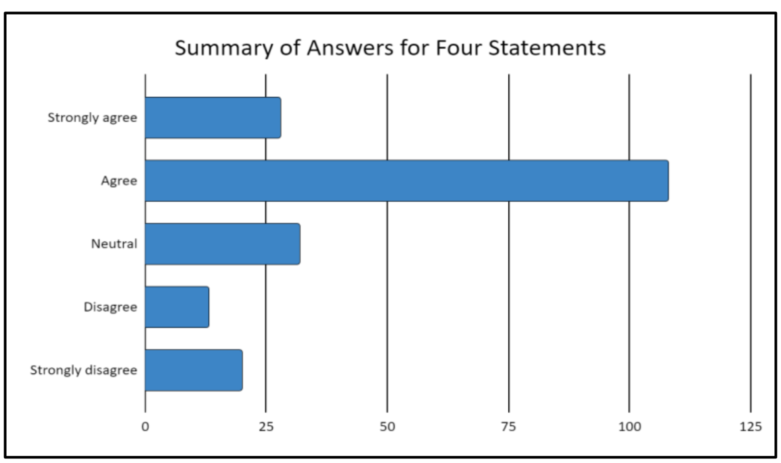

Figure 8: Summary of Students' Responses

It is seen that the majority of the students agreed that the activity helped them when learning about Frames and Machines. The breakdown of responses for each survey statement is shown in Figure 9.

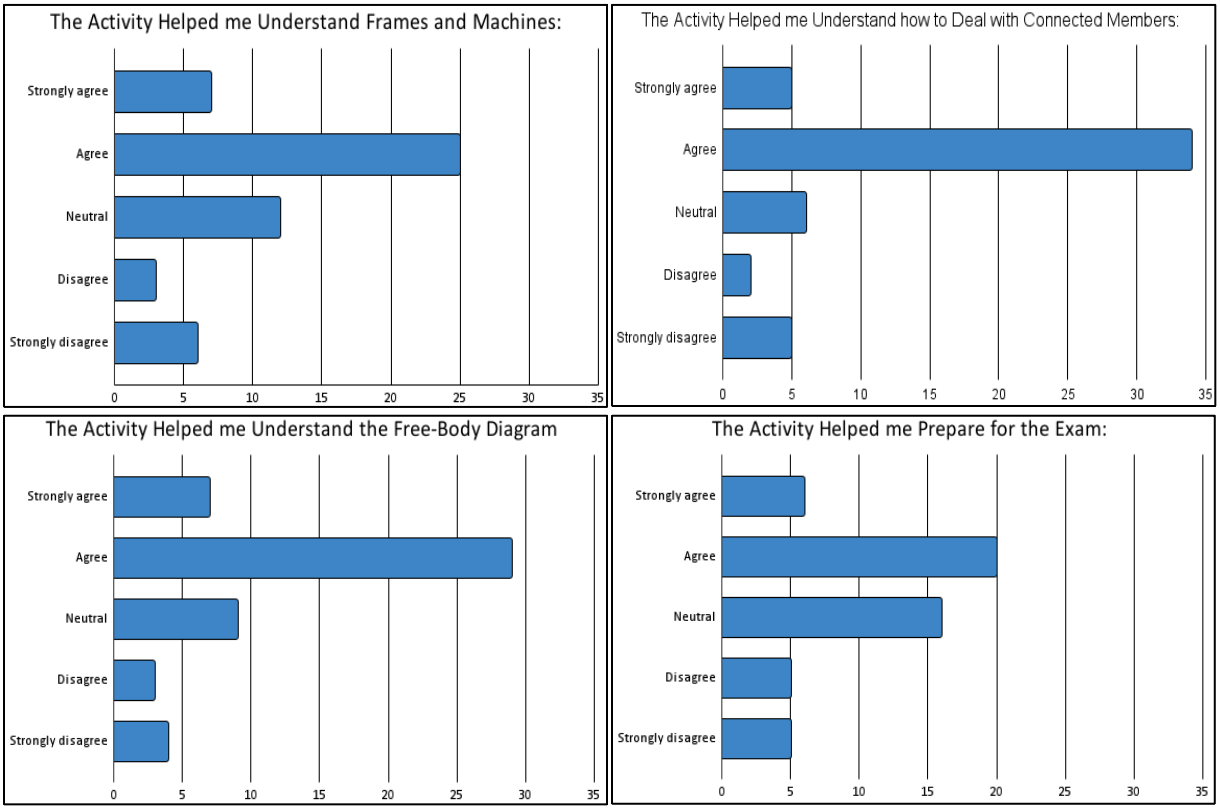

Figure 9: Student Responses to each Survey Statement

It is seen that the majority of students agreed with each survey statement. 70% of students found that the activity helped them with their understanding of FBD. The results of an open-ended question asking students about their favorite activity indicated that the developed activity on Frames and Machines was the students' favorite. They stated that the activity was beneficial because they could see the frame as a whole, and also could see the individual components, which helped them see how all the members work together. One student said that they liked it "because I think I'll be able to use this in the future". The feedback is consistent with the goals of creating the activity.

Conclusion

The previously made Statics Activity Kit [4] and the ability to reuse the previously made drawings, helped ensure the activity would be developed for students in the fall of 2022. The implementation of the activity and survey results indicated that the 3D-Printed Frames and Machines activity is beneficial to students. It helps them understand how to solve problems on Frames and Machines and learn about the importance of FBD.

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