Paper ID #25965

Work in Progress: 3-D Models with Lesson Plans

Dr. Anna K.T. Howard, North Carolina State University

Anna Howard is a Teaching Associate Professor at NC State University in Mechanical and Aerospace Engineering where she has led the course redesign effort for Engineering Statics. She received her Ph.D. from the Rotorcraft Center of Excellence at Penn State University in 2001.

Work-in-Progress: 3D Models with Lesson Plans

Abstract: Some students benefit from having a physical, hand-held model which they can hold and experiment with. A group of faculty in biochemistry at NC State has been working on a Wordpress platform where lesson plans can be paired with 3D-printable designs for students to access. We propose to build a comparable site for Engineering Mechanics. Each lesson will include:

- written explanations of the topic
- a 3D CAD file using Fusion 360 where students can access the file, see how it's built, and edit it as needed
- a brief video from Fusion 360 where the part spins or deforms
- a 3D printer file so that faculty or students with access to a 3D printer can print their own demonstrations
- a lesson plan describing a simple experiment to demonstrate the topic being discussed
- reflection questions built around the material

The proof of concept is being explored using Area Moments of Inertia and Products of Inertia. This paper presents the initial feedback from students and instructor and plans for the future.

Introduction:

The idea that hands-on models can improve learning is not new: Felder and Silverman famously included hands-on models as an example of an active teaching.[1] The notion that 3D printing can make such opportunities more available is not new either.[2] As makerspaces become regular on-campus tools for students, educators have been trying to figure out how to bring that capability into the classroom.[3,4]

I work principally with Statics in the Mechanical and Aerospace Engineering Department at NC State University where my goal has been to increase the number of students who can succeed on the first attempt through the course without lowering the standards needed to pass. In the redesign effort for that course, I've added a number of demonstrations throughout the semester to clarify common misconceptions.[5] None of these demos have been hands-on because of the large numbers in my classes each year (around 500).

As 3D printing has become available on my campus and available at prices that students can reasonably be expected to afford, I have begun looking at what can be done in basic mechanics courses for students to have hands-on demonstrations.

Current Project:

My Statics syllabus includes area moments of inertia by both integration and by composite bodies (the additive/tabular method for composite sections). Teaching the steps to fill out a chart is not the hardest part; getting students to understand why they're filling out a chart or what I_x measures proves to be considerably harder. Teaching students what a product of inertia measures is harder yet.

Figure 1. Student standing on I-Beam

Every semester I have taken demonstrations to class to try to explain the principles behind moments of inertia and how area moments of inertia measure the ability of a beam to resist bending. (see Figure 1) I have a student stand on an aluminum I-beam suspended between two chairs holding a PVC axis system. We look at the force from the student's weight and talk about how it would bend the beam. But it's still not the same thing to watch someone turn a beam as to feel the difference in your own hands.

My experience suggests that students do not find it easy to connect the work on moments of inertia that we did in class to the actual bending of actual beams. A student who can calculate the value for I often has no idea what that calculation had to do with beam bending. But when students can make the connection between the math on the page and what they know of the world through their on common sense, two things happen: They are more motivated to learn when they understand why certain math operations are required, and 2) they remember the lessons longer.[6] Area moments of inertia is a prime place for connecting students to the real world early in their engineering schooling: students learn why buildings have I-beams and not H-beams, why scaffolds are built with poles, and why no one tries to bend a ruler width-wise instead of flat (Figure 2).

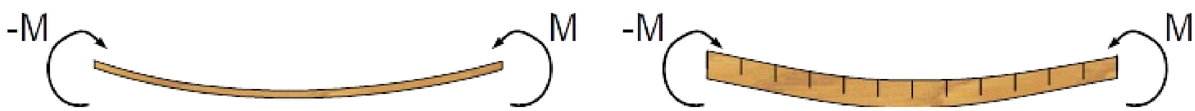

Figure 2. Two Ways of Bending a Ruler

Clearly those demonstrations I used in earlier semesters have not been sufficient for all the students to make the connections I hope for.

I was approached by Autodesk about the possibilities of using 3D visualization software in Statics. The question was posed to me: is there a place where students struggle to learn a topic in Statics that might be made easier by 3D software? After that visit with the representative from Autodesk, I started thinking about how to introduce such a 3D model into the curriculum.

At about the same time I learned of an effort by two faculty at my university to create an online clearing house for 3D materials. Claire Gordy and her team teach Microbiology and wanted to have 3D printed viruses so students could visualize what they were learning with physical objects. They proposed creating a Wordpress site where faculty could post learning materials for students and other faculty to download for a specific topic.

Our current proposal uses 3D models to teach area moments of inertia and products of inertia. This will be posted online to http://stembuild.ncsu.edu/ as a lesson plan to be shared with students and teachers. The focus is on calculating area moments of inertia and products of inertia for items that students can hold and bend.

Elements:

Building on the concepts of inquiry-based learning and varied learning styles, I set out to create a learning module with multiple avenues for students to contextualize the concept of moments and products of inertia.[1,7] The online system for hosting these lesson plans allows for written explanations, videos, and files for distribution.

A sample lesson module is found in the Appendix below. Each module includes written text, videos explaining the concepts, and video examples. Prompts throughout ask students to reflect on what they see. A module such as this should be paired with problems to calculate values for hand-held objects to increase the chances that students can make the connection between what they hold and what they calculate.

Modules have been developed for area moments of inertia and products of inertia (with the expectation of revision after more modules are developed.) Extensions to the module or perhaps additional modules for the area moment of inertia for semi-circles and integration are in progress.

The area moment of inertia module is available, allowing students to access the material as needed and at their own pace. 3D print files for students to download so they can print their own hands-on materials are also available. An example of a 3D-printed I-beam is shown in Figure 3. The module for area moments of inertia asks the students to bend the beam in two directions and to calculate exactly which way is harder to bend and how much harder using dimensions they take with a ruler.

Figure 3. 3D-printed I-beam with flexible material

The module also includes 3D-print files for cross-sections. Samples of such cross-sections are shown in Figure 4. Future modules for centroids could extend the usefulness of these modules to include drilling a hole where the centroid is calculated to be so that students can hang their models on a thread. These models are also used in the area moment of inertia module. Each of these cross-sections matches up with a homework problem requiring students to calculate inertial properties. Having a cross-section which students can pick up and rotate may help reduce the confusion between the directions of the loads and the inertial properties of the cross-sections. Video solutions are available for these specific cross-sections as well.

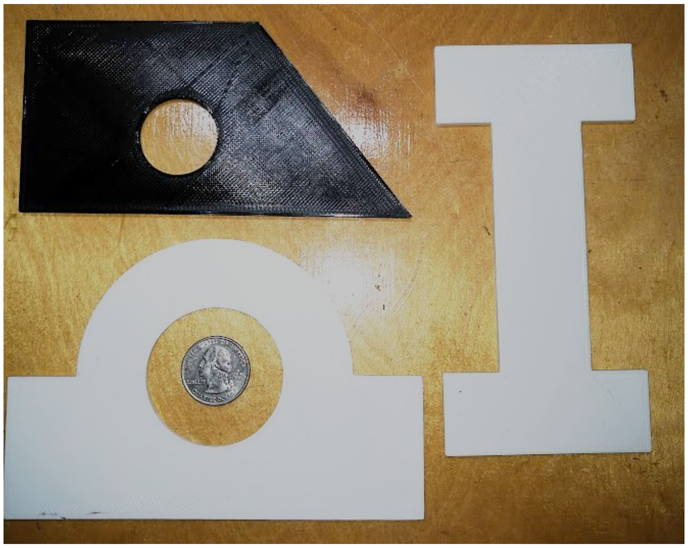
Figure 4. Flat cross-sections for beams

Assessment Plan:

The modules for the area moment of inertia and the product of inertia were used this semester. Students were handed three I-beams such as the one shown in Figure 2. The white beam was printed with a stiff material which the students could not bend. The green beam was printed using hollow sections inside. A black beam was printed with a flexible material at 100% density. Students could bend the black beam in both directions and feel immediately which direction produced more deformation.

After class, I asked the students three questions using TopHat student engagement software. (Results in Table 1)

1. Is it helpful for you to hold these in your hand to see which way these bend more easily? (5-point Likert scale)
2. Would it be helpful for you to have a model of your own? (5-point Likert scale)
3. If I gave you access to a 3D printer and the file, would you bother to print it yourself? (Assume you have not seen one in person.) (4-point Likert scale with no neutral)

This semester I taught 4 sections of Statics: two in the classroom with me in Raleigh and two synchronously in Havelock and Wilmington. The distance students are connected with a Zoom teleconference each day and have a site coordinator assistant in the classroom with them. These students were not in the classroom to handle the I-beams I passed around.

Table 1: Student Impressions

	Students in Class with Me, N = 94		Distance Students, N = 13	
	Strongly agree, Agree	Disagree, Strongly disagree	Strongly agree, Agree, N, percent	Disagree, Strongly disagree
1. Helpful to hold	75 | 80%	2 | 2%		

2. Own Model	43 | 48%	8 | 9%	11 | 85%	0 | 0%
3. Would Print	50 | 54%	43 | 46%	10 | 77%	3 | 23%

Students in class who handled the I-beam overwhelmingly found it helpful to understand the difference in bending; only 2 people disagreed that it was helpful and no one strongly disagreed. The students do not immediately see the need to have their own models. Students with their own models could experiment with the model and draw axes on it which could increase their learning in a way that a shared model cannot. Students were not polled about why they were disinclined to print their own. Cost may have been one concern; another may be lack of familiarity with 3D printers.

Students who have the ability to play during class with hands-on models often lack the interest in pursuing their own models outside of class time, time pressures being what they are for students. I was not particularly surprised to find out that students who had handled the models were still not sure they would ever print them on their own. The interesting result there was for the students who had not had a chance to handle my models where 85% said they'd want a model of their own and 77% said they'd print one on their own for the chance to handle them.

These results lend credence to the concept that students benefit (or feel that they benefit) from hands-on models of their own.

The second part of this proof-of-concept was from the product of inertia materials used in class. The product of inertia measures the resistance to warping as moments are applied. A beam with a symmetric cross-section such as the pool noodle in Figure 5 will deform under a moment in any of the three dimensions in such a way that a flat cross-section remains flat after bending or twisting. A beam with a non-symmetric cross-section such as the J-beam shown in Figure 6 will have planar cross-sections which do not remain planar after they deform. Students calculate products of inertia in Statics but commonly cannot follow the ideas of planar sections deforming.

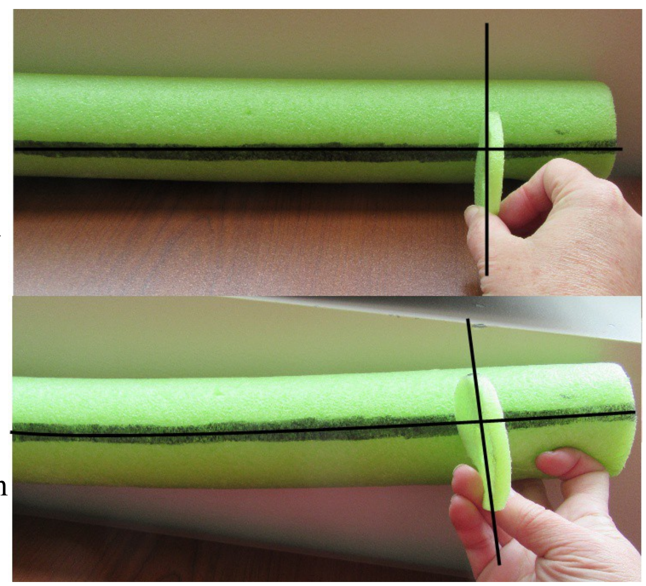

Figure 5: Pool noodle (foam) and cross-section used to show that planar sections remain planar for symmetric beams

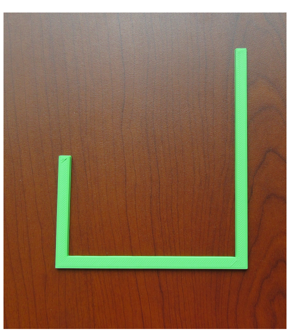

Figure 6: Printed J-beam cross-section

This semester 3D modeling allowed students to see an animation of the bending the beam with the non-symmetric cross-section shown in Figure 6. The J beam was modeled in Fusion 360 by Natania Lee, one of my prior students. She printed a physical version of the cross-section (see Figure 6) and produced an animation to let students watch the beam deform. Figure 7 shows a screen shot from the deformation animation.

After the pool noodle description, students were shown the animation to see the deformed beam. Anecdotally I can definitively say that students had a better understanding of what a product of inertia measures after they saw the deformation of the J-beam in Figure 7.

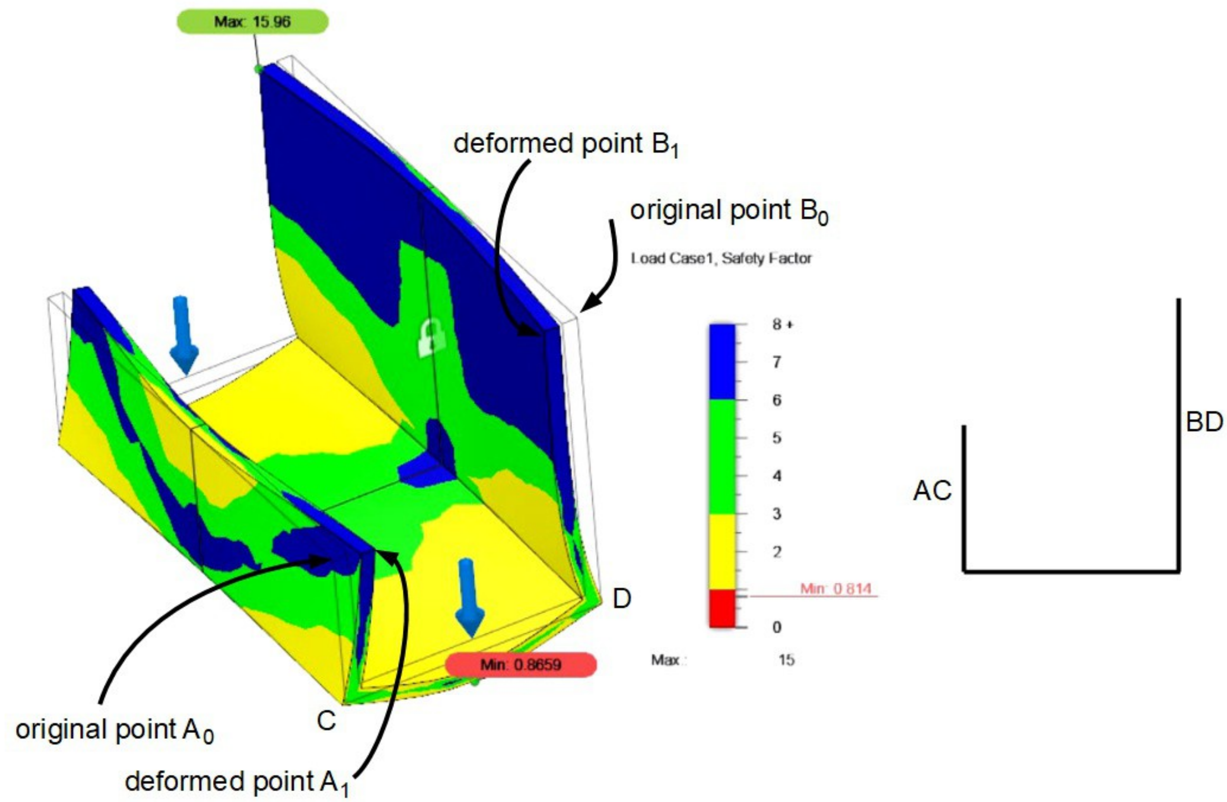

Figure 7: Screen shot from J-beam bending animation

Students were able to see on the screen that the points A and B had moved closer to the locked midsection of the beam. After the moment of inertia demonstrations, students volunteered that the shorter AC would bend more than the longer BD. This animation demonstrated that points A, B, C, and D which were all in plane when the J-beam was undeformed were no longer all planar afterwards. This experience gave some context to the homework question shown in Figure 8 where students were asked to calculate the product of inertia for the beam.

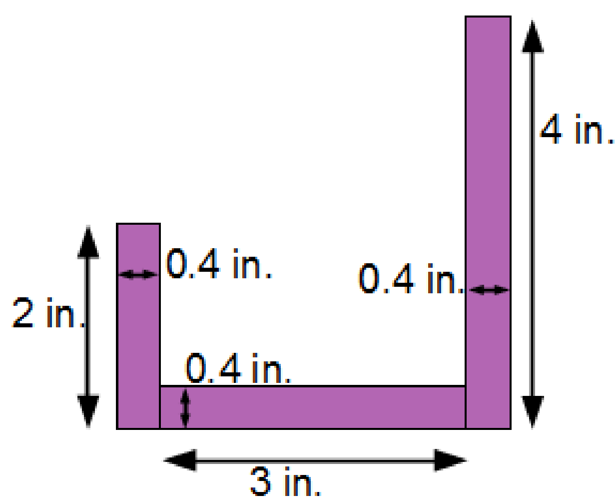

Figure 8: Homework problem to find product of inertia

Such an animation would of course be an excellent introduction introduction to Mohr's circle.

Conclusions:

This short study has provided proof-of-concept confidence that 3D models can help students conceptualize their learning. As more and more students have access to the 3D models on campus and to 3D printers so they can produce their own models to play with, lesson plans which present a tested lesson for students will be valuable for the instructors teaching Mechanics as well as for students needing additional assistance.

After the first round of student feedback is obtained, materials will be hosted on NC State's dedicated site for these materials: stembuild.ncsu.edu. Instructors or students from outside NC State will have access to the files as well as to the lesson plan materials both written and video.

We hope that producing modules such as this for the inertial properties will prove useful to students and instructors outside NC State.

With special thanks to Natania Lee who greatly assisted with 3D production.

Appendix:

Module 1: Area Moments of Inertia, stembuild.ncsu.edu

- Read *Background Principles and Motivation*.
- Watch introductory video https://youtu.be/omrmA-QGkcw
- Imagine bending a ruler. Which way would you do it more easily?
  Hands-on: Bend the ruler flat-wise and width-wise. Which way is harder to bend? Which way would you want to install the ruler in a structure to hold up more weight? Since the material and the length don't change, what does?
- Review Example 1: bending rectangle about its centroid, *PDF* or https://youtu.be/BvEu0fpLfdc
- Read *Ruler Bending about its own Centroid*.
- Read *Note about Axes*.
- Write a brief paragraph relating the axes and the bending loads to ruler in your own hands.
- Print the 3D flexible I-beam.
  - Bend the I-beam in your own hands in two directions.
  - Draw the axes directly onto your printed beam so that the z axis is along your beam. (Make sure it's a right-handed coordinate system so that when you look at the cross-section you see a regular x-y axis system.)
  - Draw an FBD of your beam to specify which direction your loads are acting in when you bend the beam in each of the directions.
  - Which way does the beam bend more? About which axis is that? (Remember the direction the moment is applied is where your thumb points.)
  - Which area moment of inertia are we talking about for each bending direction? (I_x and I_y)
- Review Example 2: bending rectangle about its baseline, https://youtu.be/nD1ZMlrgJ_k
- Watch the video animation of the stress in the bending I-beam from both directions. Lay

your printed I-beam on top of your pencil so you can push down on either side and bend the beam over the pencil as is shown in the video. Which direction deflects more easily?

- Write a brief paragraph explaining why the moment of inertia about a rectangle's baseline is bigger than about its centroid. Relate this to the ruler in your own hands.
- Draw a one-inch line on each side of the I-beam. Bend the I-beam about the y-axis. Note that one of your inch lines is longer than the other side.
- Read *Beam Bending and the Neutral Axis*.
- Read *Parallel Axis Theorem*.
- Lay your flexible I-beam flat on the table. If you push on the top two ends, the beam experiences a bending moment; the top surface of the beam will bend a bit but the bottom surface can't deform. The neutral axis is where the deformation is zero.
- Practice problem: Find the moment of inertia of the triangle about its baseline. Solution https://youtu.be/UjC4xjr0jCc and https://youtu.be/MApovKX7CIc
- Read *Composite Bodies*.
- Print the 3D flat piece matching the cross section of your I-beam.
    - How does the flat piece match up to your flexible I-beam?
    - Draw the axes directly onto your flat cross-section.
- Review Example 2: H-beam moment of inertia https://youtu.be/lC4D4U3dliU
- Calculate the area moments of inertia for your cross-section about both axes. Use your ruler to estimate the size of the beam. (Does the length of the beam measurement appear in your calculations for the area moments of inertia?)
- How much harder it is to bend your printed I-beam about one axis vs the other? Which way would you install an I-beam to hold up a building?
- Homework problems are available upon request.

References:

[1] R. Felder and Silverman, Linda K., "Learning and Teaching Styles In Engineering Education," J. Engr. Education, vol. 78, no. 7, pp. 674–681, 1988.

[2] H. Lipson, "Printable 3D Models for Customized Hands-on Education," Mass Customization and Personalization (MCPC), p. 6, 2007.

[3] M. Galaleldin, F. Bouchard, H. Anis, and C. Lague, "The impact of makerspaces on engineering education," Proceedings of the Canadian Engineering Education Association (CEEA), 2016.

[4] V. Wilczynski and R. Adrezin, "Higher Education Makerspaces and Engineering Education," in Volume 5: Education and Globalization, Phoenix, Arizona, USA, 2016, p. V005T06A013.

[5] Howard, A.K.T., "Demonstrations for Class Time for Flipped Statics." Proceedings of the 2016 ASEE Southeast Section Conference, Tuscaloosa, AL, March 13 - 15, 2016.

[6] N. R. Council, How people learn: Bridging research and practice. National Academies Press,

1999.

[7] B. P. Self, J. M. Widmann, and G. C. Adam, “Increasing Conceptual Understanding and Student Motivation in Undergraduate Dynamics Using Inquiry-Based Learning Activities,” presented at the 2016 ASEE Annual Conference & Exposition, 2016.