AC 2011-860: INTEL: PRESENTING ONLINE 3D EXERCISES IN A STATICS CLASS

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InTEL: Presenting Online 3D Exercises in a Statics Class

Abstract

While difficulties in the Statics course arise for several reasons, our project seeks to address the problem of context. Our hypothesis is that all students generally, and women and minorities particularly, are more likely to do well in statics when the problems are placed in the context of real world usefulness. Towards that end, we have been developing InTEL (Interactive Toolkit for Engineering Education), a computer-based manipulable environment that supports teaching and learning in statics by mapping images from real-world environments to abstract free-body diagrams for 2D and 3D equilibrium problems. To the best of our knowledge, there are very few online tools students can use to study 3D equilibrium problems. Yet 3D is an important part of statics, and many students struggle with it. We would like to present our software and discuss some of the issues we encountered while developing its 3D module.

Introduction

It has long been known that women and URMs (under-represented minorities) tend to avoid engineering as a major, resulting in a severe and detrimental lack of diversity in the populations of both student and professional engineers. The main reasons for this are: a technical experience gap relative to their white male peers [1]; lower self-confidence than their white male peers [2]; poor quality of classroom experience that leaves them feeling isolated, unsupported and discouraged [3]; not perceiving the practical applications of engineering [2]; not perceiving the creativity and inventiveness of engineering [2]; not perceiving the social usefulness of engineering, particularly to help people [2].

This problem is especially acute in statics, which is typically the first engineering course most students take. It's a foundational course that introduces the engineering approach to problem solving, which is based on a deep understanding of the free-body diagram (FBD) and its pivotal function in describing and constraining a problem. Sadly however, students routinely leave this course having learned to "plug and chug" or jump to a mathematical equation without first defining the problem in a diagrammatic form that articulates the underlying principles. In short, they rely on rote application of equations without understanding that the mathematics are an outcome of a preliminary step of model formation. Difficulty in this fundamental cognitive act of model building can cause a lack of confidence and a diminished sense of self-efficacy that is particularly problematic when amplified by the gender and URM issues described above.

Issues with learning statics are not new and much research has been done to try and remedy the situation[4-9]. Yet none of these interventions specifically attempt to address the way statics is presented, by emphasizing engineering's "specific and tangible contributions to society and in bettering local communities, our nation, and the world" [10] in order to help women's and URM's sense of "fit" and persistence in their engineering majors.

Our work attempts to remedy this by leveraging computer animations to explicitly show students how statics is tied to everyday life and everyday situations they may encounter. One of the advantages of computer animations is that they provide an important opportunity for students to manipulate objects and tools – something that is often lacking, especially for women and URMs who are typically not taught or encouraged to take apart machines as they grow up. Another advantage of computer animations is that they effectively scaffold students' efforts at model building and connect abstract problems with multiple real world applications – for example, the mechanical model for an arm bent at the elbow at 90 degrees and supporting a weight in the hand is the same as that of a leg bent at the knee at 90 degrees supporting the weight of the foot. This can help teach students how to model a physical system, what should be included in the model and what can be discarded, and why.

A third major advantage of computer animations is in their power to handle 3D (three dimensional) systems in a way that is simply impossible to do in a textbook, on a piece of paper or on a classroom board. 3D equilibrium is a relatively small part of the statics semester, yet it is crucial for many engineering majors (especially those who will next deal with 3D motion, such as mechanical, aerospace, and biomedical engineers). And of course, the ability to see in 3D is very important in everyday life, such as when one buys furniture – which must fit into the room it is intended for!

To the best of our knowledge, no work thus far has been done to address 3D equilibrium learning via computer simulations. The goal of this paper is to present our software's 3D module, discuss some of the programming challenges we have encountered, and present our latest data on student scholastic success with the intervention.

3D Equilibrium Modeling

Our funding was awarded on March 1 2007. We have created a public website where we post completed exercises as well as news of the project. The public website is viewable at http://intel.gatech.edu and the exercises can be accessed at http://intel.gatech.edu/toolkit. Our group and the various tasks each sub-group performs have been described in our past ASEE conference papers[11-13].

Some of the exercises we have developed and now assign to students every semester are listed in Table 1 below:

TOPIC	PROBLEM(S)
Moment in 2D, Free-body Diagram	Seesaw
Equilibrium of 1 rigid body or Frame	Arm & Purse
Truss: Method of Joint & Method of Section	Minneapolis Bridge
Distrib. Load, Centroid	New Orleans Levee, Space Station
Frame	Keyboard
Combined Frame & Truss	Bicycle
Friction	Spiderwoman

Table 1. List of online exercises

Additional exercises are also given to students as non-credit practice, so they can get used to the software. Since the inception of the software three years ago, we have developed exercises for almost every statics topic, except two: 3D equilibrium and shear force and bending moment (V-M) diagrams. The purpose of this section is to explain some of the challenges we've encountered as we develop the 3D module.

As anyone who teaches statics knows, 3D equilibrium usually comes in two flavors:

1. Problems with 4, 5 or 6 unknowns on the FBD, such as a boom supported by a ball-and-socket joint and two or three cables. These problems must be solved by using the full equilibrium solution, i.e. all three force equations and all three components of the moment equation, though some of them might be linear combinations of the others so the system of equations stays well-defined (same number of independent equations as unknowns).

2. Problems with 7 or more unknowns on the FBD, such as a door supported by two hinges. Since 3D equilibrium only provides up to 6 independent equations for a single body, all unknowns cannot be solved for, and only a subset will be solvable. Typically, only one is asked for, usually the force that causes rotation of the object along a specific axis (for example, in the case of the door, that would be the axis of rotation of the door). To solve for that one unknown, only one equation is needed instead of the usual six. That equation is the sum of moments about the axis of rotation of the object (i.e. the axis of rotation of the door), and it requires taking the dot product of the regular moment equation (about a point). So this second category of problem requires the combination of cross and dot products, something many students struggle with.

In a sense, the 2nd type of 3D equilibrium problem is only a special case of the 1st one, since each component of the moment equation is simply its dot product with each of the base vectors. However, the dot product is not explicitly done when we separate the components and equate them individually to zero, therefore many students miss the subtlety.

From a programming standpoint, the fact that a 3D problem may necessitate six equations or just one makes a big difference. When we started the design of the InTEL software, the screen was developed to accommodate the FBD of one body and its associated three equations of equilibrium for 2D problems (see Figure 1). We felt that since the majority of the semester is spent in 2D equilibrium, first for one body then with multiple interconnected bodies (trusses and frames), the screen should be designed to provide space for three equations. Scrollbars are provided, both horizontally and vertically, to accommodate exceptionally long equations or formulaes.

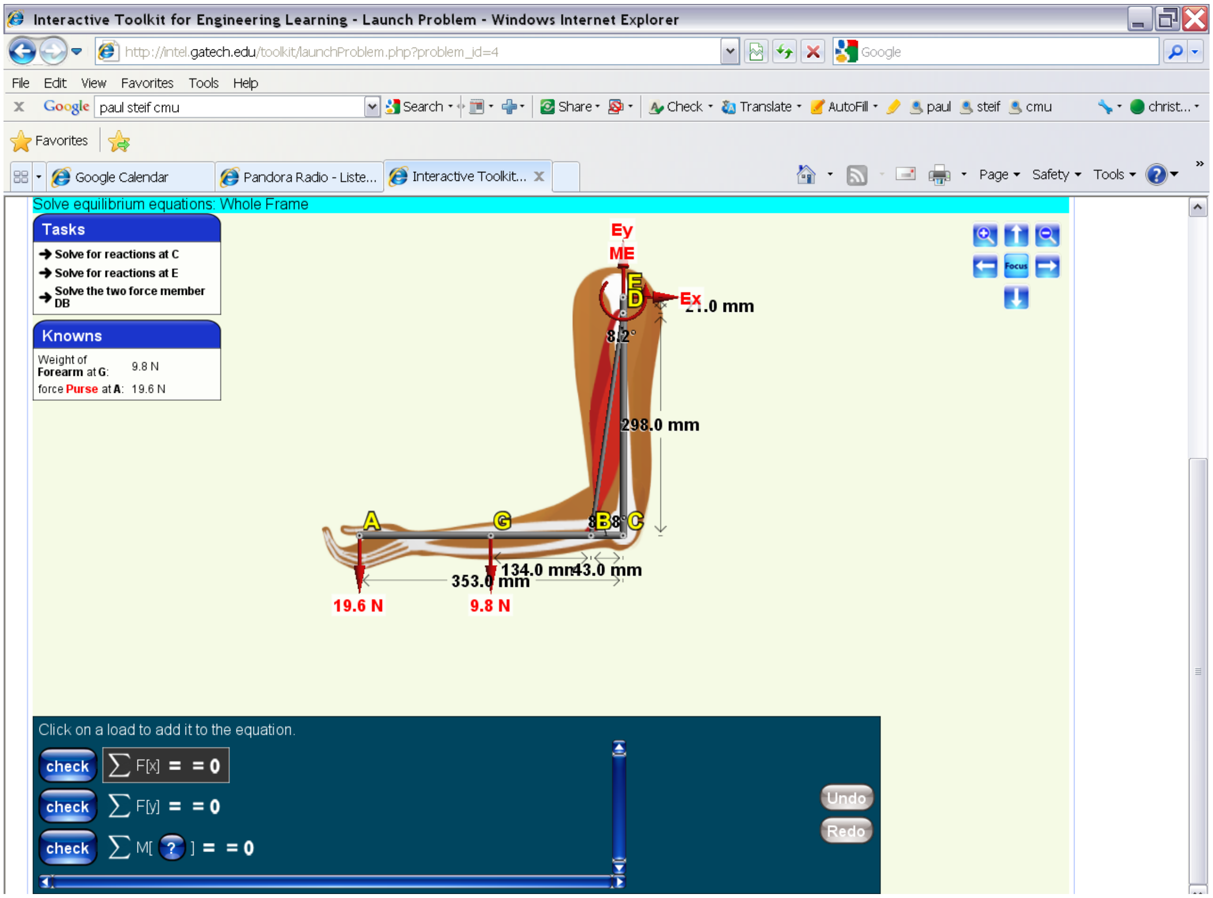

Figure 1 – Arm and Purse problem (2D equilibrium), with 3 independent associated equations

When we developed the friction module, a fourth equation had to be added to accommodate the (optional – depending on the type of friction problem) condition of impending motion by using the vertical scrollbar (see Figure 2) and by providing a new button by which students could add the formula $f = \mu N$, where f is the maximum friction force, μ is the static coefficient of friction, and N is the normal force acting at Spiderwoman's feet.

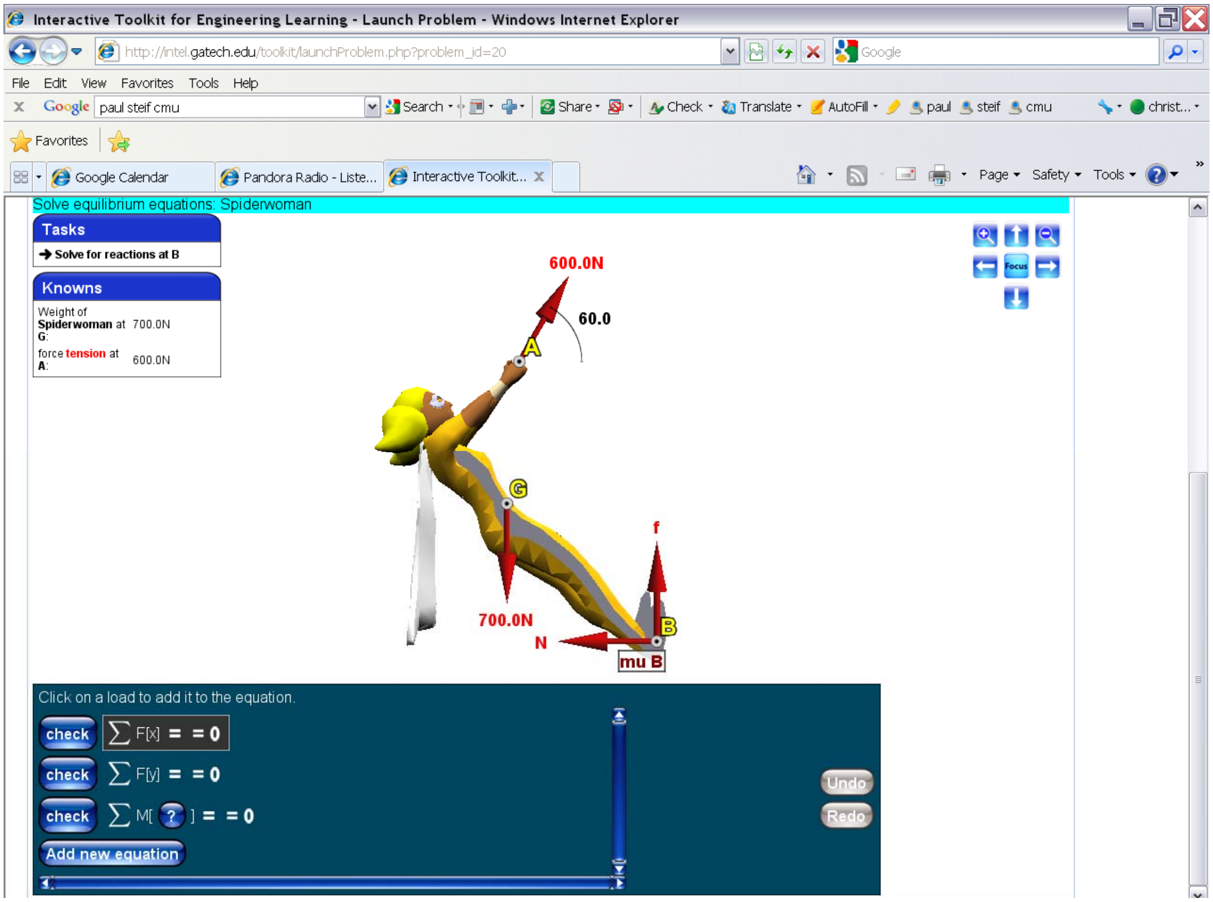

Figure 2 – Spiderwoman problem (friction) – notice special button to add additional equations

When the button ‘Add new equation’ is clicked, a new line appears, with blank left- and right-hand sides that the student must fill himself or herself (see Figure 3):

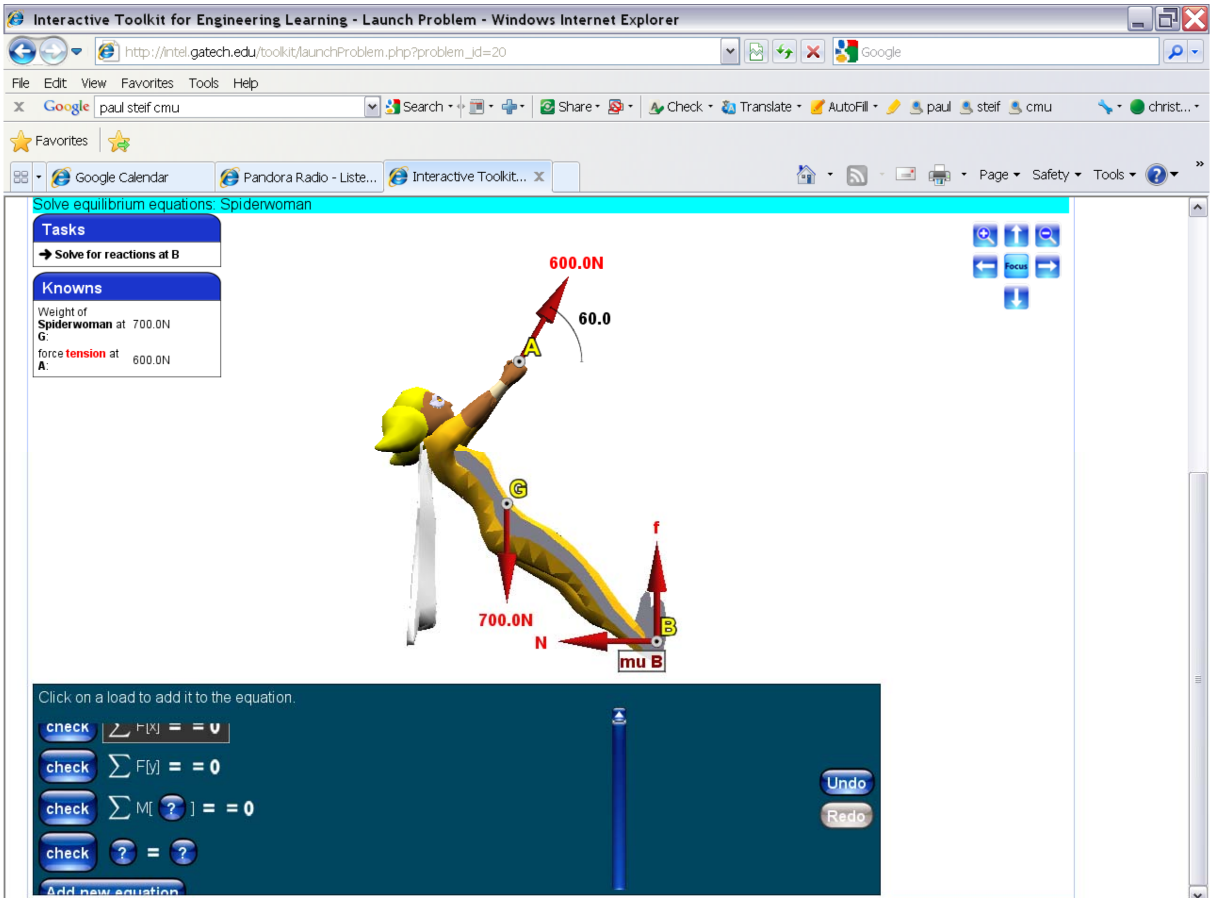

Figure 3 – Input of a new equation

The same process can be used for 3D, but that would involve telling the students ahead of time what type of problem they have (i.e. whether it necessitates a dot product or not), something the instructors felt was a disservice. In the end, we decided students would first work on the FBD, then once the FBD was correct, the students would be prompted to decide whether they need a six-equation formulation or just a one-equation formulation.

Another issue with the six-equation formulation is that the instructors wanted the students to first write out the overall moment equation as a series of vectors, forces crossed with their associated moment-arms and (potentially) couples, then calculate the cross-products explicitly (on a piece of paper, not online), and then enter each component of the fully calculated moment equation in its own equation line. Therefore, instead of six "lines" with which to enter each equation component, the software screen needed to provide at least seven lines instead, three for the force equation components, three for the moment equation components, and one for the general moment equation with explicit (but as yet uncalculated) cross-products (see Figure 4).

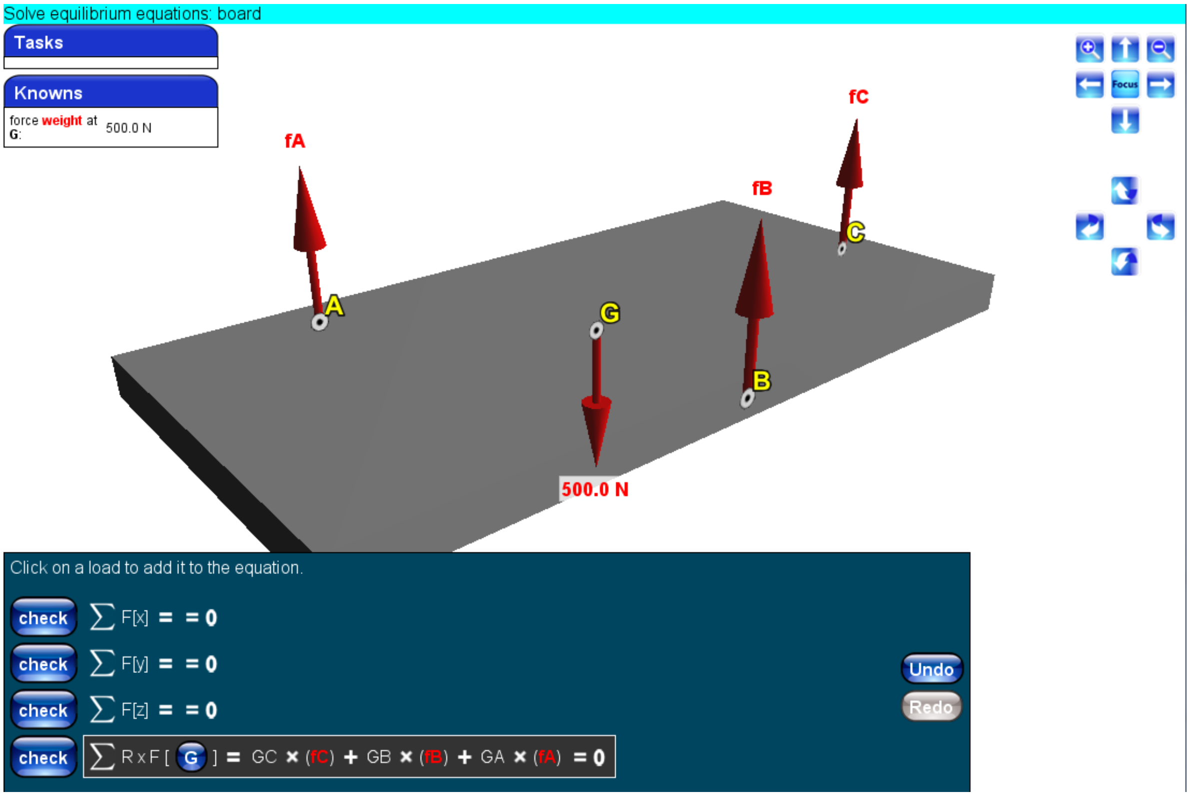

Figure 4 – Moment equation in 3D with explicit vector formulation

The problem in Figure 4 is that of a plate weighing 500N supported by 3 people (located at points A, B, C) exerting vertical forces pointing straight up. Finally, a 3D FBD requires a "joystick" to be able to navigate the 3D environment and rotate in any direction (see Figure 5).

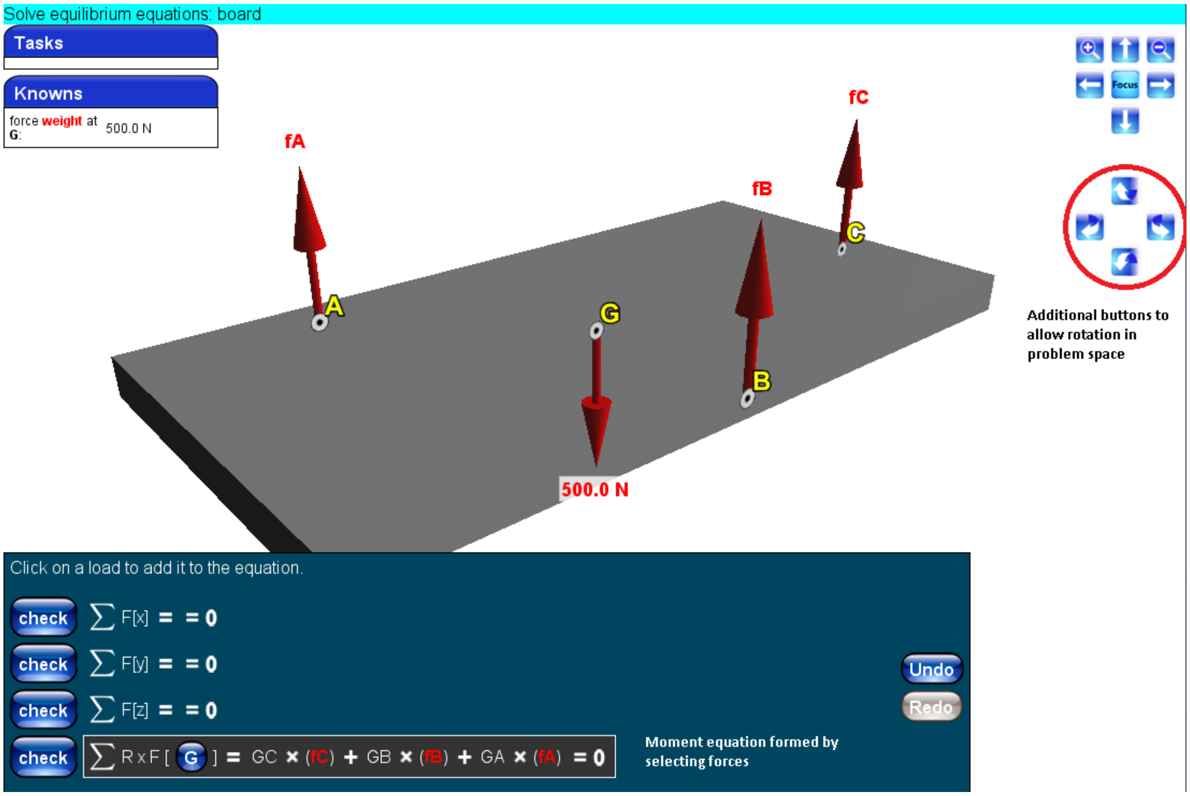

Figure 5 – Rotation controls in 3D (top right corner)

In this manner, InTEL allows students to approach 3-D statics problems in a visual, hands-on manner. The student can use the rotation controls to pan and rotate the camera view on the problem space. Students compose the moment vector equation directly within the software by selecting the forces and constructing the moment arms. The InTEL software gives a clear presentation of the mathematics underlying difficult 3D problems and illuminates the process of solving them.

Feedback from students

As reported in last year's ASEE proceedings[13], we currently have about a 70% rate of success on the online problems (that is, about 70% of the students in each section given the online exercises complete them and find the correct answers). This includes the problems listed in Table 1 (not 3D problems, which aren't fully developed yet). Last fall, that number increased to 86%. Informal student feedback is also solicited by passing out paper surveys in class, three times per semester. The response rate ranges from 80 to 90% and the answers are anonymous. The surveys ask to specify gender and ethnicity and has been published in last year's ASEE proceedings[13].

Some noteworthy comments we received in Fall 2010 semester include:

1. From the section that received the intervention, to the question *In what ways was the computer a resource for your problem solving?*:
    - "it made me check my work after every step, therefore I can catch a mistake early and not learn the wrong way"

- "it helps you by telling you what may be wrong. It's used as a guide."
- "Helped to understand concepts rather than get caught up in the math"

2. From the section that received the intervention, in answer to the question *The computer was not helpful when:*
    - "it crashed"
    - "trying to solve the problem, it's not very flexible"
    - "computer errors; slow loading (frustrating)"
3. From the control section, in answer to the question *In what ways was the textbook a resource for your problem solving?*:
    - "I can look at example problems"
    - "It has answers in the back"
    - "lots of problems/examples"
4. From the control section, in answer to the question *The textbook was not helpful when:*
    - "checking for mistakes"
    - "there are no problems similar to the one being solved"
    - "This textbook is vague"

We suspect that the online tool, by forcing students to first make sure their FBD is correct before jumping into the equation mode, better scaffolds their ability to develop meta-cognition in statics. It helps students develop discernment as part of the modeling process. In contrast, textbooks seem to encourage superficial "feature mapping," whereby students focus on a trivial aspect of the problem ("Does it have a pulley like the problem I'm assigned to solve?") to guide their solution strategy, rather than rely on deep metacognitive strategies ("What part of this structure should I draw the FBD of, in order to isolate and solve this force?")

As stated in last year's paper, when the students first encounter the online problems, they struggle with computer glitches, missing Java plug-ins, and learning how to maneuver in the program. As they get more proficient and used to the applet, they tend to enjoy the software and most report preferring it to the textbook. In particular, women and URMs seem to prefer the software at higher rates than white males, which was one of our goals for this project[13].

We also conducted a grade analysis and compared course GPAs between males, females, and URMs per section (differentiating between the sections that used the software, called "Applic," versus those which didn't, called "Control"). This analysis was conducted for spring and fall semesters, in 2008, 2009 and 2010, for a total of 8 Control sections and 10 Applic sections, and the tables 2 and 3 reflect averages based on the aggregate grade data. "Enrolled" lists the total number of students that signed up for the class, and "Graded" reflects the total number of students who received a final grade for a class (i.e. it doesn't include the students who dropped the class at any point in the semester). All sections are taught the same way by the same instructor (Dr. Valle), so instructor variance was removed from the analysis. The GPA is calculated on the basis of A = 4, B = 3, C = 2 and so on.

Cohort code	URM (alt)		Enrolled	Graded	% URM	Group GPA
Applic	White or Asian (W,Z)		430	409	79.4%	2.93
Applic	URM (H,B)		58	56	10.9%	2.55
Applic	Foreign-born		36	35	6.8%	2.97
Applic	Two or more (T)		11	10	1.9%	2.60
Applic	Unknown (U)		5	5	1.0%	2.40
			540	515	100.0%	2.88
Control	White or Asian (W,Z)		434	419	82.6%	3.02
Control	URM (H,B)		53	47	9.3%	2.49
Control	Foreign-born		23	23	4.5%	3.00
Control	Two or more (T)		15	14	2.8%	2.50
Control	URM (I,P)		3	3	0.6%	3.00
Control	Unknown (U)		1	1	0.2%	2.00
			529	507	100.0%	2.96

Table 2 – Grades of URMs versus non-minorities, test versus control sections

One can see, from Table 2, that URMs do slightly better (GPA of 2.55 vs 2.49) with the software, and that white or Asian populations do slightly worse (GPA of 2.93 vs 3.02). From Table 3, women do slightly better (GPA of 3.07 vs 2.9) with the software, while men do slightly worse (GPA of 2.82 vs 2.97).

Cohort code	Gender	Enrolled	Graded	% M/F	Group GPA
Applic	US-Male	396	375	72.8%	2.82
Applic	US-Female	108	105	20.4%	3.07
Applic	Foreign-born	36	35	6.8%	2.97
		540	515	100.0%	2.88
Control	US-Male	381	362	71.4%	2.97
Control	US-Female	125	122	24.1%	2.90
Control	Foreign-born	23	23	4.5%	3.00
		529	507	100.0%	2.96

Table 3 - Grades of female versus male students, test versus control sections

It is very important to understand that these are preliminary results, and that within the overall course experience, the intervention is very small (less than 25% of the homework problems are done online, and the homework grade is only 5% of the overall class grade – see Appendix A for details) so it can only have minimal effect on overall class grade. Also, not every statics topic is addressed in the software as of yet (as stated earlier, both 3D and V-M diagrams are still missing). Still, those results are encouraging and we plan to continue the analysis as the software is finally fully developed. We also plan to probe deeper into gender and ethnicity information.

We are encouraged that our intended target population, women and under-represented minorities, like the applet – even more so than white males – and moreover, that preliminary results seem to indicate the software has a positive impact on their grades relative to that of white males. This is a very encouraging result. Our goal, as stated earlier, is to help attract and retain women and URMs to engineering, and as such we do not want to make the applet gender or race neutral. We did not design the applet with the intention of making it equally attractive to all our students, but rather with the goal of it providing yet a different way to learn statics that some students will respond to better than others. The intervention is limited enough (as explained earlier, less than 25% of 5% of the overall class grade) that its impact is small. The overall class experience remains very traditional: largely lecture-based, and exams based on an extensive library of past exams given by both instructors.

Conclusion and Future Work

In this paper, we discussed developing an online module to help teach 3D equilibrium in a statics class. This module is part of a more extensive software that provides additional exercises covering nearly all statics topics. Each semester, one or two statics sections are assigned the online problems as part of their homework assignment, and one section is assigned a traditional homework out of the class textbook. All sections are taught by the same instructor. They're given surveys to assess informally how they feel about the intervention, and their grades are tracked.

Our results show that even though the software doesn't quite cover all statics topics yet (3D equilibrium and V-M diagrams are in development), most students prefer it to the textbook. Grades seem to be positively affected by using the software, for women and URMs. While these results are very positive, it is important to remember the intervention is very small (most of the class grade is determined by performance on in-class, paper, traditional exams) and its effects need to be confirmed.

Based on our work so far, we hope to soon finish the software (cover all statics topics) and offer its library of exercises to any statics instructor who wishes to try it. We also want to continue assessing its effects on grades of various groups of students, and disseminate our findings to interested parties.

We believe that our software allows for the possibility of a risk-free environment for experimentation and practice. Not all students will enjoy the online environment, but the hope is that by emphasizing "game-like" visuals and the various ways statics is everywhere in everyday life, we will help retain more at-risk students in engineering and show how engineering can be both relevant and rewarding. Ultimately, we do not think this software, or any software for that matter, should completely replace the traditional way of teaching statics. Instead we hope that this software will be used as one part of the class "tools," an additional technique to offer students who like this approach to the class material, given to supplement the traditional lecture-based class format and not replace it. Preliminary results are encouraging.

Literature Review

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Appendix A - Homework assignments in statics class

		Homework List			
		ALL SECTIONS			
Homework Topic	**Hwk #**	**Book**	**Dr. Valle's Word**	**Book Only (control)**	**Online (test)**
Moments	1	3.7	Test 19, Pbs 1&2; Test 1, Pb 3		
Equilibrium of rigid bodies	2		Test 40, Pb 1; Test 52, Pbs 1&2	4.19	arm & purse
Centroid & distributed loads	3		Tests 9 & 10: Pb 1 each	7.36, 4.46	space station, levee
Truss and Frame	4		Test 53, Pbs 1 & 2	5.51, 4.162	bike, keyboard
V, M diagrams	5	5.186	Tests 44 & 45: Pb 1 each; Test 54, Pb 1		
Friction	6		Tests 44 & 45: Pb 2 each; Test 54, Pb 2	6.1	spiderwoman