AC 2011-1198: INTEL: INTERACTIVE TOOLKIT FOR ENGINEERING LEARNING CONTEXTUALIZING STATICS PROBLEMS TO EXPAND AND RETAIN WOMEN AND URM ENGINEERS

Janet H. Murray, Georgia Tech

Professor in Digital Media Graduate Program, Georgia Tech, interaction designer, and author of Hamlet on the Holodeck: The Future of Narrative in Cyberspace (1997) and Inventing the Medium: Principles of Interaction Design as a Cultural Practice (MIT, forthcoming in 2011). She is Director of Georgia Tech's Experimental Television Lab where she has created prototypes for PBS's American Experience, POV, and the History Channel. Before coming to Georgia Tech she directed educational computing projects at MIT with funding from NEH, Annenberg/CPB, and the Mellon Foundation.

Christine Valle, Georgia Institute of Technology
Sue Rosser, San Francisco State University

Sue V. Rosser currently serves as Provost at San Francisco State University, where she is also Professor of Sociology and of Women's Studies. From 1999-2009, she was Dean of Liberal Arts at Georgia Tech, where she held the Ivan Allen Dean's Chair of Liberal Arts and Technology and was Professor of Public Policy and of History, Technology and Society. Author of twelve books, she has also published more than 130 journal articles on women, science, technology, and health.

Wendy C. Newstetter, Georgia Institute of Technology

Wendy C. Newstetter is the Director of Learning Sciences Research in the Wallace H. Coulter Department of Biomedical Engineering at Georgia Tech.Her research focuses on understanding learning in interdisciplines towards designing educational environments that develop integrative problem solving.

Laurence J. Jacobs, Georgia Institute of Technology

Associate Dean for Academic Affairs, College of Engineering

John D. Leonard II, Georgia Institute of Technology

John Leonard is Associate Dean for Finance and Administration with the College of Engineering and Associate Professor with the School of Civil and Environmental Engineering.

Dr. Sneha Veeragoudar Harrell

InTEL: Interactive Toolkit for Engineering Learning Contextualizing Statics Problems to Expand and Retain Women and URM Engineers

[authors names omitted for review purposes]

DRAFT for January 19 2011 Submission

NSF Engineering Education
Award #0647915
Dates: 2007-2011

The InTEL Project aims to improve Statics learning generally and to increase representation of women and Under-Represented Minorities (URMs) in Engineering by creating interactive problems drawn from real world contexts that demonstrate the usefulness of engineering. The interdisciplinary team has developed exercises for the introductory Statics course that serves as most students' first introduction to engineering problem solving.

Currently, the U.S. engineering workforce remains 90% white and male; engineering, in particular, has not attracted women and URMs. Baccalaureate degrees received by both URMs and women in engineering peaked in 1999-2000 and have trended downward since then[1] A study conducted by Engineers Dedicated to a Better Tomorrow used the NSF WebCASPAR database to document that although about one half of earned baccalaureate degrees in S&E as a whole go to women, in physics, engineering, engineering technology, and computer science, these rates dropped to one in five[2]. While in 2008 women earned 18.5% of engineering degrees, substantial variation occurred among the sub-disciplines in engineering. Civil Engineering (22.5%), Electrical (11.0%) and Mechanical Engineering (11.8%) lagged behind Chemical Engineering (33.3%) and "all other engineering fields" (27.6%)[3] . A study by the Engineers Dedicated to a Better Tomorrow revealed that although the percentage of baccalaureates in S&E awarded to URM-combined (16.4%) is just slightly below that seen in all academic disciplines (16.9%), the percentage of baccalaureates awarded to URM-combined considering engineering and the five closely related fields (14.7%) is significantly less than the corresponding percentage seen for S&E as a whole (16.4%) [4]. Although some variations occur among the racial/ethnic groups, Blacks are especially underrepresented in each subdiscipline of engineering [3].

A substantial body of research has uncovered factors that deter women from engineering, including the following: a technical experience gap relative to their male peers [5], lower self-confidence than their male peers[6]; poor quality of classroom experience that leaves women feeling isolated, unsupported and discouraged [[6]; not perceiving the practical applications of engineering [6]; not perceiving the creativity and inventiveness of engineering [6]; not perceiving the social usefulness of engineering, particularly to help people [6]. URMs experience similar deterrents, particularly concerning the request for practical applications and the need to overcome the experience gap [4]. On the other hand, research documents that women and URMs are attracted to engineering when they can see its "specific and tangible contributions to society and in bettering local communities, our nation, and the world" [7]. The ABET criteria, especially criterion 3, for better engineering education, overlap with strategies that have been shown to be particularly effective for the recruitment, success, and retention of women and minorities [8], such as offering students extended experience in experimentation, observation, and holistic problem-solving, through interactive methods.

The InTEL project is aimed at using the properties of digital media to create interactive and socially contextualized exercises to support model-based reasoning about Statics. We began by identifying representative student errors in creating the Free Body Diagram, which is the basis of understanding Statics problems, and creating interventions that address these specific points of confusion. Over three years we tracked students who used the exercises and measured them against a control group who used only a conventional textbook. We gave both groups survey questions at the beginning and end of the semester aimed at capturing their attitudes toward engineering and their confidence in their own ability to become successful engineers. We also administered short, targeted questionnaires after key assignments to capture students' attitudes toward computer-based and textbook-based problems. Finally, we analyzed retention and performance statistics for students in the two groups, comparing them to baseline data, and looking for differences in the experimental and control groups including those related to gender and race. This paper offers an overview of our research questions and methods, and a preliminary report of our outcomes and findings.

Research Questions

We started with three main research questions:

1. Can integrating interactive learning tools into a foundational Statics course foster and sustain engagement in engineering among women and URMS?

2. Can interactive learning tools increase representation of women and URMs in engineering majors?

3. Can software environments:
    - be designed and used to support the development of diagrammatic reasoning in introductory Statics courses?
    - be designed to support the development of 2D to 3D reasoning and manipulation?
    - afford the kinds of contextualization that clarify real world usefulness?

Team Members

The project has been conducted by an interdisciplinary team and draws on methods from learning science, engineering, digital media, and gender research. Sue Rosser, the originating PI, does research in women and minorities in science and engineering; Larry Jacobs and Christine Valle are engineers directly involved in teaching the target course, and John Leonard analyses student data for the College of Engineering; Wendy Newstetter and Sneha Veerdagoudar Harrell do research in cognition and learning; and Janet Murray, the project manager, is a professor of digital media. Most of the students who have worked on the project, including Calvin Ashmore, the lead programmer and system designer, have been drawn from Georgia Tech's graduate program in Digital Media.

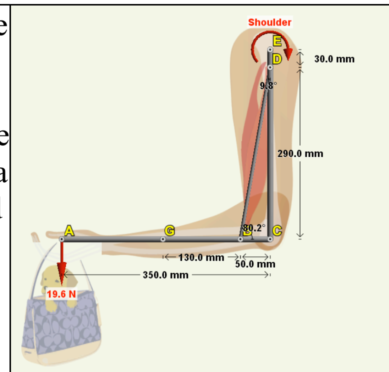
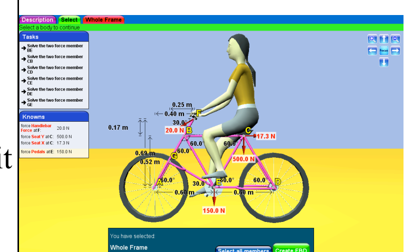
Materials

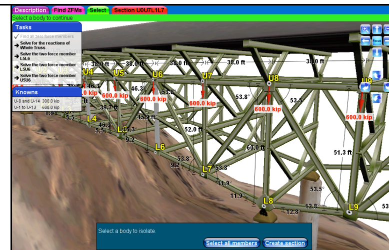
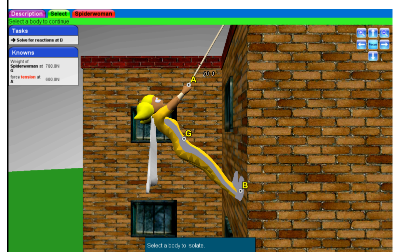
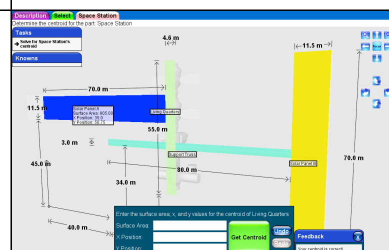
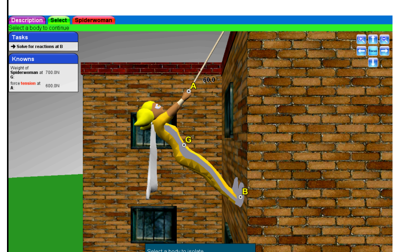
InTEL Toolkit.

The InTEL software was developed to support students' capacity to learn the *process* of statics problem solving and develop more expert like habits of mind (Nasir, XXXX) over the course of the semester. The problems developed within the toolkit reflect the Georgia Institute of Technology Statics course syllabus. Over the course of the first three years the InTEL toolkit was expanded, increasing the amount of time students were able to spend with computer-based interactive statics demonstrations and homework problems. Table 1 summarizes the development process.

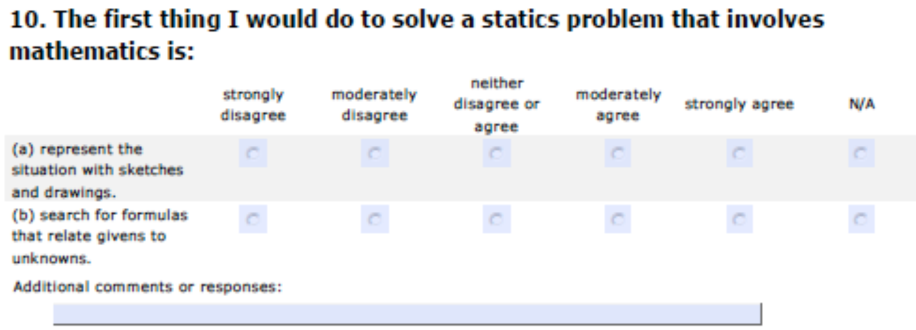
Table 1 Development of Interactive Exercises

Terms	Development Focus	Sample Problem

Summer 2007 to Spring 2008	Simple Equilibrium problems were deployed in a functional online system linked to a database to record student work. Students were invited to use the applet as an extra credit exercise, and instructor used it as a demonstration tool in the classroom. Other problem scenarios were identified and the problem development begun to cover the work of the entire course.	 Equilibrium: Purse and Arm  Equilibrium: Tower of Pisa
Summer 2008 to Spring 2009	Exercises were implemented for Distributed Loads and Frames. Development began on Truss problems. A major step forward was the implementation of a state system, that allows students to save their work to resume later and to undo and retry action. The website was also redesigned to allow the instructor more control over assignments and better tracking of student progress. Offered 6 exercises for extra credit Fall ’08 Offered 3 required, 3 extra credit exercises Spring ‘09	 Distributed Load: New Orleans Levee  Frame: Bicycle

Summer-Fall 2009	Implementation of exercises for Trusses and Friction. Offered 4 required, 1 extra credit, 5 practice exercises Fall ‘09	 Truss: Minneapolis Bridge 
Spring 2010 to Summer 2010	Implementation of Centroid exercises. Offered 7 required, 1 extra credit, 6 practice exercises Spring ‘10	 Centroid: International Space Station
Fall 2010 Spring 2011	Assignment of Exercises for Equilibrium, Distributed Loads, Frames, Trusses, Friction, Centroids Development of 3D problems underway. Offering 6 required, 1 extra credit, 9 practice exercises Spring ‘11	 Friction: Spiderwoman

Pre and Post Survey. Throughout 4 year project the same pre and post survey was distributed to students in Christine Valle’s courses. The instrument used was a modified version of the Arizona Views About Science Survey (VASS) Survey (http://modeling.asu.edu/R&E/Research.html) authored by Ibrahim Halloun and David Hestenes [9, 10]which was originally created for use with grades 8-16 and later adapted for different disciplines such as physics, chemistry, biology, general science, and mathematics. VASS was designed to “survey student views about knowing and learning science, and to assess the relation of these views to student understanding of science and course achievement” and probes students views along both scientific and cognitive dimensions such as validity of scientific knowledge, scientific methodology, learnability of science, reflective thinking, and personal relevance of science, using questions that elicit responses along a five-point scale. All items are on a five-point scale that are designed to present contrasting alternatives that respondents must choose amongst (See Figure 1).


10. The first thing I would do to solve a statics problem that involves mathematics is:

	strongly disagree	moderately disagree	neither disagree or agree	moderately agree	strongly agree	N/A
(a) represent the situation with sketches and drawings.						
(b) search for formulas that relate givens to unknowns.						

Additional comments or responses:

Figure 1 Question from the InTEL pre-course and post-course Student Attitude Survey, a customized variant of the Arizona VASS.

In addition, we conducted *Think Aloud Protocols* in the first four semesters of the project in order to identify the components of expert and student problem-solving. We collected data concurrently (while solving the problems) and retrospectively (asking subjects to reflect on their solution methods shortly afterwards [11]. In the 5th-8th semesters of the project we deployed a new assessment instrument in an effort to examine the students’ learning process using the computer-based problems and to compare it with those of students using the traditional textbook problems. We designed a short, 5 minute survey asking specifically how the tools were a resource and what preferences students had for future problem solving. In the 5th and 6th semesters we administered 3 surveys per semester; in the 7th and 8th semesters we decided to administer 2 surveys per semester in order to avoid participant fatigue.

Procedures

As the overall toolkit of computer-based problems grew the intervention expanded from 1-2 demonstrations given by the instructor in the first semester to half a dozen required computer-based homework problems by the end of the study and just as many available for optional practice (see Table 2).

Table 2 Interactive Exercises Deployed to Students Fall 2008-Fall 2010

Problem/concept	Fall 2008	Spring 2009	Fall 2009	Spring 2010	Fall 2010
Archer	Practice	Practice	Practice	Practice	
Arm + Purse/equilibrium	Practice	Assignment	Assignment	Assignment	Assignment
Awning				Practice	Practice

Bicycle/frame	Extra Credit	Assignment	Assignment	Assignment	Assignment
Bookshelf				Practice	Practice
Bridge/truss			Extra Credit	Assignment	Extra Credit
Keyboard		Assignment	Assignment	Assignment	Assignment
Levee/distributed load			Assignment	Assignment	Assignment
Match-Up			Practice	Practice	Practice
Merry-Go-Round			Practice	Practice	Practice
Pisa Tower/equilibrium	Practice		Practice	Practice	Practice
SeeSaw	Practice	Practice	Practice	Practice	Practice
Space Station/centroid					Assignment
Spiderwoman/friction				Assignment	Assignment

In Year 1 and 2 we conducted open-ended think aloud protocols. Students were presented with problems to solve (See Figure 2) in the context of one-to-one semi-structured clinical interviews [12]. Students were given a whiteboard wall (Year 1) or a large sheet of paper (Year 2) on which to work out their solutions.

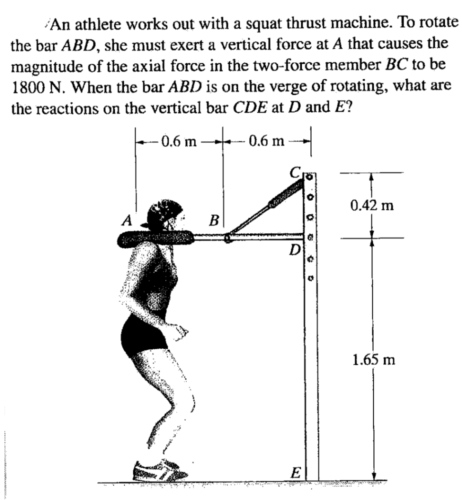


Figure 2 Sample paper-based problem used in the first set of think aloud protocols

The interview protocol included a structured set of questions – increasingly suggestive prompts – to continuously elicit students' verbalizations of their thought processes, even when they appeared to be 'stuck.'

- Level 1: explain what you are currently thinking.
- Level 2: explain what you have just finished doing.
- Level 3: explain your representation of the problem (e.g. after making a diagram)

In Year 3 we implemented the Assignment Response Survey. In both Fall and Spring semesters, after the 1st, 2nd, and 3rd computer-based homework items were due. a researcher attended the lecture and distributed/collected the Assignment Response Survey to all participants.

In Year 4 after the 2nd computer-based homework item was due and then again at the end of the semester, a researcher attended the lecture and distributed/collected the survey to all participants.

Years 1-4 Throughout the 4 years some things were consistent such as the demonstration of the toolkit, although it became more robust over time. For example, in semester 1 there was only 1 or 2 problems that could be demonstrated by the instructor but by the 6th semester the instructor had the option of choosing from a number of functional problems/scenarios.

Years 1- 4: We collected modified Arizona FOSS data at the beginning and end of each semester.. This was a consistent instrument used throughout the life of the project.

Data Collection for Assignment Response Surveys
The raw data from this study consists of institutional records for each student participant (e.g., grades earned, major, year, retention in major, time to graduation, etc.), video data for think aloud protocols conducted with select participants, video data of experts thinking aloud on problems, pre/post attitudinal surveys for each semester, artifacts collected from surveys given in the 5th and 6th semesters.

Data Analysis
We conducted both quantitative and qualitative analysis [13, 14] in order to examine the institutional records, surveys, and think aloud protocols. We utilized a combination of techniques inspired by grounded theory [15] and micro-genetic analysis for survey data collected in the 5th, 6th, 7th, and 8th semesters of the study. We focused on students' citations of ways of understanding statics, their use of imagistic reasoning, and their report of what resources were most valuable in their problem solving. Specifically, we analyzed the data corpus, including the full think aloud video data, their 5th-8th semester Assignment Response Surveys, as well as students' artifacts many times over to carefully select segments that could contribute to building our understanding of the students' reasoning along the following lines of inquiry:

1. Reasoning based on embodied experience, did students draw upon their "intuitive" understanding of cause and effect in the physical world as they experienced it through their physical interactions with the real world.
2. Imagistic reasoning, that is a proclivity towards fully developing and utilizing the Free Body Diagram for problem solving and statics reasoning,
3. Evidence of intermediate abstractions, similar to those created by expert problem solvers, that allow engineers to move from real world to Free Body Diagram and only then to the mathematical solution.

Preliminary Results

Preliminary results indicate:

1. Students in the control group who used the textbook demonstrated a pattern matching approach to problem solving. They attempted to map qualities in a homework problem to patterns in an example problem in the textbook, often relying on superficial resemblances.
2. Students in the experimental group who were exposed to the computer-based intervention reported focusing less on the solution and more on learning the method, by relying on the hints and immediate feedback they received from the computer-based tool. They reported that they valued the feedback within the homework situation where they had privacy to make errors and where they would not otherwise have access to expert advice.
3. Students in the experimental group also indicated that the software helped them to visualize the problem, which made the problem more comprehensible to them.
4. 85% of students achieved successful problem completion in the computer-based exercises.

Conclusion

Engagement with the project increased the confidence of the participants that digital media could be used to create exercises that connected engineering with real world settings and events. Moving from the textbook to the web allowed us to distribute our own exercise, and making the exercises within a modular system allowed us to add new exercises to illustrate the same principles with multiple scenarios, using the same underlying representations of Free Body Diagram and mathematical formulae. It also allowed us to model the correct solution method because we could prevent the students from moving to the mathematical formula stage before they had successfully solved the Free Body Diagram. Based on our preliminary assessment, the students' self-reports reinforced our sense that the computer-based exercises worked the way we intended them to work, reinforcing visualization of the Free Body Diagram, formation of intermediate abstractions, building confidence by affording a safe place to fail and feedback on how to correct errors, and discouraging plug and chug approaches. We are also encouraged by the high problem completion rate and by the self-reports of greater understanding of the process of thinking like an engineer among the students in the experimental group.

Because the degree of intervention increased over the four years of the project, we think it will take longer to discover significant patterns of attitude change, overall performance, and retention, but we will have preliminary results of our assessment instruments by the time of the final paper submission. We also suspect that the intervention will benefit all students in the course, not just women and URMs because of the many advantages of the digital problems over the textbook presentation.

We will also continue to track retention in engineering after the end of the current project in August 2011.

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