From Tootsie Rolls to Broken Bones: An Innovative Approach for Active Learning in Mechanics of Materials

JULIE LINSEY
Texas A&M University

AUSTIN TALLEY
University of Texas at Austin

CHRISTINA WHITE
Columbia University

DAN JENSEN
United States Air Force Academy

KRISTIN WOOD
University of Texas at Austin

ABSTRACT

Active learning enhances engineering education. This paper presents rationale, curriculum supplements, and an approach to active learning that may be seamlessly incorporated into a traditional lecture-based engineering class. A framework of educational theory that structures the active learning experiences and includes consideration of learning styles and preferences is discussed. The paper presents innovative example activities for courses in engineering mechanics designed to meet a variety of student needs and diverse learning styles. In total, twenty-eight activities were developed and range from quick hands-on activities which can be done during lecture to multimedia tools. Activities were targeted at the difficult concepts for mechanics of materials. Typical assessment results, from three institutions of higher learning, are provided to illustrate the effectiveness of these activities. Results show that the Active Learning Products (ALPs) increase student learning as compared to a traditional lecture. ALPs are also effective at various types of institutions of higher learning.

Keywords: active learning, mechanics of materials, hands-on

1. INTRODUCTION AND MOTIVATION

In many cases, active learning approaches for engineering education improve student learning [1]. Many engineering professors are aware of the benefits active learning provides and desire to incorporate more of these activities and experiences into their classes [2]. Indeed a wide variety of organizations and funding agencies that promote science education strongly recommend that institutions of higher education provide greater opportunities for authentic, interdisciplinary, and student-centered active learning [3–8].

There is considerable literature that addresses the advantages of integrating hands-on experiences in an engineering curriculum [9–21]. Unfortunately, ready to use activities and manipulatives are frequently not available for a given subject or engineering concept. Often professors' packed schedules can be a constraint in aligning the resources available to develop new student-centered activities. A review of literature finds that some professors are concerned about the implementation of active learning versus traditional lecture-based courses for this reason and others [22, 23]. The large class size at universities can also make many active learning techniques seem daunting and impractical especially to educators who are used to lecture-based instruction.

Contrary to these initial concerns, research suggests that professors who transition their pedagogy to include active learning experiences in engineering education have multiple positive benefits for both the educator and the students. Active learning nurtures synchronically learning engineering concepts and skills instead of learning them in series as is done in lecture-based instruction. This pedagogical approach to engineering education also creates an efficient forum for assessment because students can self-assess and professors can use the active learning process to quickly obtain an authentic evaluation of the student's learning. This forum for assessment is especially valid when grading large amounts of work is a challenge and also since some students do not perform well on written exams. Competencies future engineers can foster from active learning are professional knowledge and skills; application of engineering concepts; organization and management skills; and communication skills [24–27]. Another positive effect of active learning in engineering education experiences is that it improves retention, persistence, and promotion of science career pathways for underrepresented groups [24–27]. Hence, this paradigm shift in pedagogy and curricula is imperative to promote and support diversity in the engineering classrooms and in preparing global engineers for the future.

This paper presents an approach to hands-on active learning, with pedagogy founded solidly on educational theory, which is a series of activities for mechanics of materials that can be seamlessly incorporated into large lecture classes. This approach overcomes many of the hurdles for incorporating active learning into a traditional engineering classroom. We seek to create a series of activities that may be easily incorporated into a range of classroom settings, from small classes built around active learning to a large, traditionally lecture format learning environment. To meet this goal, twenty-eight active learning products (ALPs) for mechanics of materials were devised. These activities focus on the important and difficult engineering concepts of the topic. This paper begins with a summary of the key educational theories and their implications for the development of ALPs. Next, an overview of the ALPs approach is given followed by example ALPs. Each ALPs falls into one or more of the five categories for ALPS: Thought Experiments, Investigations, Hands-on Activities, VisMOM Software, or Opportunities for Creativity. Finally, the evaluation of the ALPs is briefly overviewed providing evidence for the effectiveness of this approach.

2. GUIDING THEORIES

The key to effective development of innovative educational approaches is their foundation in learning theories. A number of theories guide the creation, assessment and improvement of our ALPs. The focus in this paper is on the ALPs and not the method to create them or a detailed assessment of them. A brief overview of the assessment is presented at the end of the paper. Applicable educational theories range from facilitating active learning to understanding an individual's learning styles. Each theory has implications for the development of ALPs. In Figure 1, three learning theories

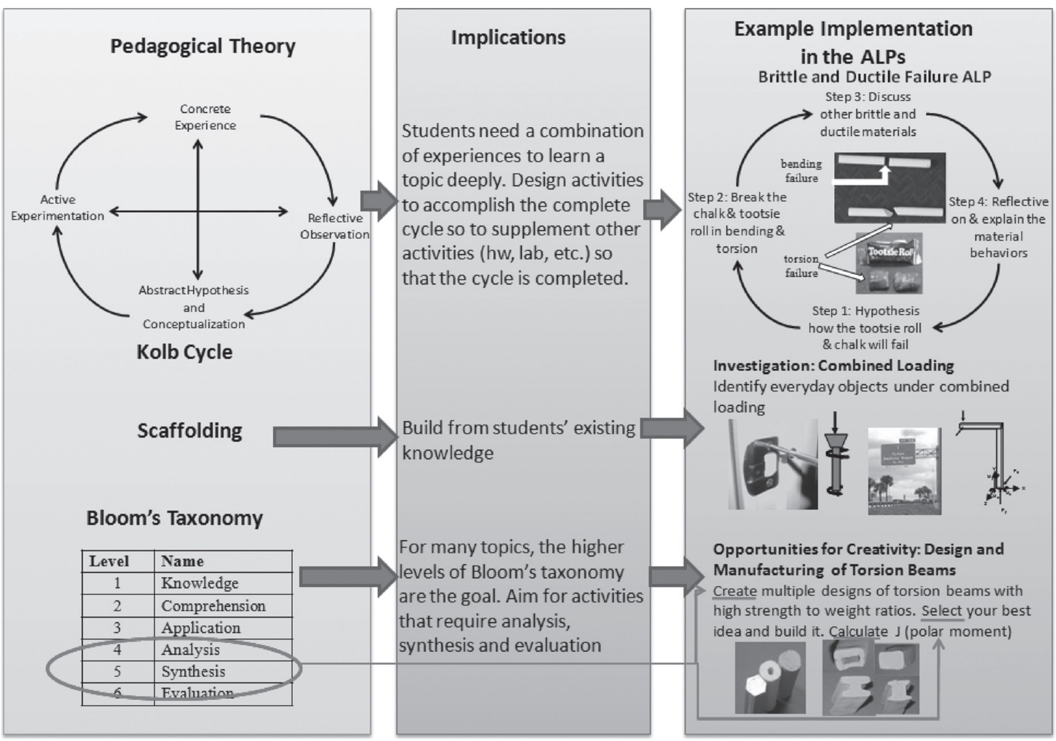


Figure 1. Pedagogical theory guides the development of the active learning activities.

are presented with implications and example implementations within an ALP. For example, one of the guidelines resulting from the Kolb model of learning is that students need a combination of different learning experiences in order to understand a topic deeply. This suggests that ALPs should be designed to incorporate the complete cycle or they should be designed to compliment other classroom activities. The example implementation, shown in Figure 1, is for the Brittle and Ductile Failure ALP (see Section 4.3 for a more detailed description of this activity). This activity guides the students around Kolb's learning cycle. First students are asked to hypothesis how the chalk and Tootsie Roll will fail under bending and torsion loads. Next, the students cause the Tootsie Roll and chalk to fail. Examples of other brittle and ductile failures are then discussed. Finally students are asked to reflect on why the two materials failed differently. In the following section the various pedagogical theories and their implications for ALPs creation are discussed.

2.1. Scaffolding

The term "scaffolding" encompasses the idea that new knowledge is best assimilated when it is linked to previous experience [28, 29]. A well-planned flow of material that builds on itself and integrates real-world examples obviously helps provide this "scaffold" for learning. Implications for ALPs include creating activities where students identify everyday experiences and objects where a given theory applies. For example, in Figure 1, for the topic of combined loading, students are asked to identify everyday objects that experience combined loading (see Section 4.2 for more details of this activity).

2.2. Deductive and Inductive Learning

The terms "deductive learning" or "inductive learning" refer to learning from general to specific or visa-versa. For example, showing the theory followed by working an example is a form of a deductive process. Most courses use deductive approaches. The literature argues that this approach is not always appropriate, stating that a mix of the two approaches provides a better learning environment [30]. Many of the ALPs were designed to be used in both modes so that the instructor may select either an inductive or deductive presentation. The professors' notes for each ALP contain suggestions for how the particular ALP can be effectively incorporated into a class.

2.3. Kolb Cycle

The Kolb model describes an entire cycle around which a learning experience progresses [31, 32]. The goal, therefore, is to structure learning activities that will proceed completely around this cycle, providing the maximum opportunity for full comprehension. This model has been used extensively to evaluate and enhance engineering teaching [33, 34]. The cycle is shown in Figure 2. Many ALPs

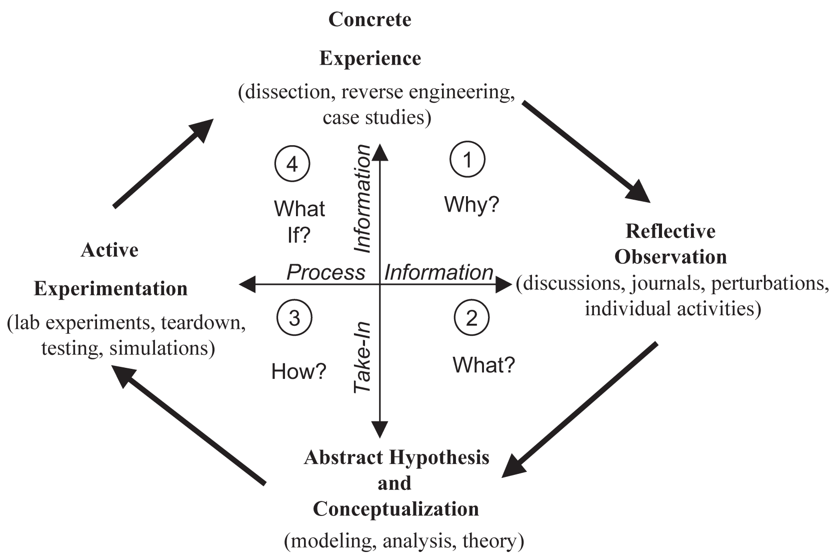


Figure 2. Kolb Cycle.

are designed to provide learning experiences covering all the steps in the Kolb cycle. Multiple Kolb steps are often missed in the traditional lecture classes and can be incorporated through the addition of ALPs.

2.4. Principles of Design for Multimedia

A number of principles for design have been developed for understanding and learning from multiple forms of media. In combination with pedagogical theory, these design guidelines facilitate the design of hands-on activities. While these guidelines are focused on design for multimedia, they apply very well to the design of the ALPs.

Guidelines for Multimedia Design (text, diagrams, etc.) [35, 36]:

1. Spatial Contiguity Principle: Present corresponding text and illustrations near to each other rather than far apart.
2. Guide the users in parsing graphical and symbolic representations, for example, exploded diagrams. This assists the user in decomposing a representation accurately into its sub-elements.
3. Make connections between elements and their behaviors. In a mechanical domain, this is the physical interaction between components.
4. Create representations with close proximity. Different representations of the same entity should be close together in space and time. An audio commentary should be simultaneously presented with an animation. Textual descriptions can be linked to diagrams.

5. Use novel visualizations to make the causal chains of events explicate. Complex mechanical systems with branching and merging causal chains are difficult for novices.
6. Encourage mental animation of static media prior to showing animations. Show snapshots of a system's operation or ask questions about how the system works.
7. Time animations at a user's pace. The presentation speed of an animation should match the user's comprehension speed. Users should have control over the speed of an animation or the animation should be broken down into chucks where the user can pause or replay.
8. Hyperlinks to the basic physical principles governing a given system should be provided.

2.5. Bloom's Taxonomy Overview

Bloom's taxonomy gives six levels at which learning can occur ranging from the lowest level of listing or reciting knowledge to the highest level of evaluation [37]. In general, higher levels correspond to a more advanced or mature learning process. Thus, we aspire to focus our instruction in higher education toward the upper levels. The ALPs allow us to assist students in moving higher on the Bloom's Taxonomy. Many of the ALPs require students to analyze, evaluate, and create based on theory taught in class.

2.6. Social Constructivism

The ALPs are framed within a social constructivist framework in an effort to create engineering education experiences that (1) help students to construct deeper understanding of theoretical

Level	Name: Description
1	Knowledge: List or recite
2	Comprehension: Explain or paraphrase
3	Application: Calculate, solve, determine or apply
4	Analysis: Compare, contrast, classify, categorize, derive, model
5	Synthesis: Create, invent, predict, construct, design, imagine, improve, produce, propose
6	Evaluation: Judge, select, decide, critique, justify, verify, debate, assess, recommend

Table 1. Overview of Bloom's Taxonomy.

[AQ1] AU: Please provide citation of Table 1.

concepts in connection to practical experiences; (2) facilitate students' engineering skills; and (3) develop students' capabilities and dispositions for engaging in collaborative project-based inquiry and critical thinking skills [38]. To assimilate new information and incorporate it into the existing knowledge, students need to restructure their knowledge for themselves [39] as fundamentally created through active learning. This social constructivist approach to teaching assumes that students learn most effectively by engaging in carefully selected collaborative problem-solving activities where the educator facilitates and coaches instead of being a transmitter of knowledge (often through lecturing). Although there are many variations on the use of collaborative problem solving in education, most share some common characteristics [40, 41]: (1) students' learning is anchored in the first-hand experience of engaging with realistic problems, projects, cases, simulations, and experiments; (2) students construct or restructure their conceptions by elaborating and explaining them to others in order to resolve conflict and controversy or to co-construct conceptions [42, 43]; (3) dialogue and negotiation of shared understanding are central to the process; and (4) the purpose of the activity is not merely problem solving, but learning through the co-construction of knowledge that may be generalized beyond the specific problem [38]. Furthermore, using ALPs in engineering education extends tenets of social constructivism into a model of learning built upon communities of practice [44, 45] where learners are socialized into the practice of the community (in this case, engineering) through collaboration, direction, and support from an experienced practitioner.

2.7. Learning Styles and Learning Preferences

Three theories are used to understand and evaluate student learning styles and preferences, Felder-Soloman's Index of Learning Styles [32, 46, 47], VARK [13] test and Myers-Briggs Type Indicator [48]. The Felder- Soloman's Index of Learning Styles is composed of four dimensions (active/reflective, sensing/intuitive, visual/verbal, and sequential/global) (Table 2). The ALPs are designed to meet the needs of students with a range of learning styles. A particular approach to teaching will often favor a certain learning preference. It is therefore important to conscientiously incorporate a variety of approaches to meet the various learning preferences. As an example, instructors' teaching styles often favor sensing over intuitive learning styles. ALPs are designed to impact all student learning styles effectively.

The VARK test serves as a catalyst for reflection by the student [13]. The student takes a simple thirteen question multiple choice preference test that is aimed at discovering how they prefer to receive and process information. After taking the test, the student receives a "preference score" for each of four areas. The first area, Visual (V), indicates student preference in receiving information from depictions (information in charts, graphs, flow charts, symbolic arrows, and other devices that instructors use to represent what could have been presented in words). The second area is Aural

ACTIVE	REFLECTIVE
Doing something active with it --discussing, applying, or explaining it to others	Thinking about it quietly first
SENSING	**INTUITIVE**
Learning facts	Discovering possibilities and relationships
VISUAL	**VERBAL**
See--pictures, diagrams, flow charts, time lines, films, and demonstrations	Words--written and spoken explanations
SEQUENTIAL	**GLOBAL**
Gain understanding in linear steps	Learn in large jumps - suddenly “getting it.”

Table 2. Felder-Soloman’s Index of Learning Styles.

(A). This area indicates the student’s preference for hearing information. The third area, Read/Write (R), shows a student’s preference for information displayed as words. The fourth area is Kinesthetic (K). In short, this area indicates a student’s preference for “learning by doing.” By definition, the “K” area refers to a student’s preference related to the use of experience and practice (simulated or real). The scoring of the test allows for the student to show mild, moderate or strong learning preferences for each of the four areas.

The Myers-Briggs Type Indicator (MBTI) includes four categories of preferences (introvert/extrovert, sensing/intuition, thinking/feeling, judgment/perception) [48–50]. Although MBTI categorization is well-established, its use as an indicator of the way people learn is far less common. The sensing/intuition category provides insight into how a person processes information. Those who prefer to use their five senses to process information (sensors) are contrasted with those who view information in light of either its place in an overarching theory or its future use (intuitors). This sensor vs. intuitor category is seen by most researchers to be the most important of the four categories for learning [15, 19]. The ALPs are designed to be effective across a variety of learning styles and personality preferences. To verify this, we have correlated learning styles, personality preferences, and ALPs effectiveness in our assessment work. This assessment work is briefly discussed below.

3. ACTIVITY LEARNING PRODUCTS (ALPS)

Thus far, a total of twenty-eight activities covering various topics for mechanics of materials are constructed. Although the importance of active learning activities is well recognized, little formal guidance in the form of a systematic approach for development exists [51]. To facilitate our development process and to provide a tool to assist other professors in creating their own ALPs, an ALPs design method was created (See Linsey et al., 2006 for details of the method [52]). A complete set of ALP materials including student handouts, detailed professor notes, and quick reference cards, are available at the Active Learning Products for Engineering Education website (www.me.utexas.edu/~alps/). Surveys of professors who teach mechanics of materials, a review of literature, and examinations of existing textbooks elucidate some challenging concepts for students. In an effort to address ways to teach and learn these challenging concepts, each ALP is targeted specifically for a concept. The ALPs are designed as a supplement to other educational approaches, including lecture, lab, and other activities.

Each activity includes handouts for the students, a set of professor's notes, and a quick reference card for the professor (Figure 3). Each student handout details the learning objectives, required materials, the procedure for the activity, and pertinent questions. The professor's notes include possible student responses, salient topics to emphasize, questions to ask during the activity, and extensions to each activity including suggestions for mini-projects. One other key element of the professor's notes to aid in the ease of use is the assignment context. The assignment context suggests ways the activities may be implemented. Depending on the activity, the ALP may be integrated in-lecture (either individual or group), as homework (individual or team), as a mini lab or as a design competition.

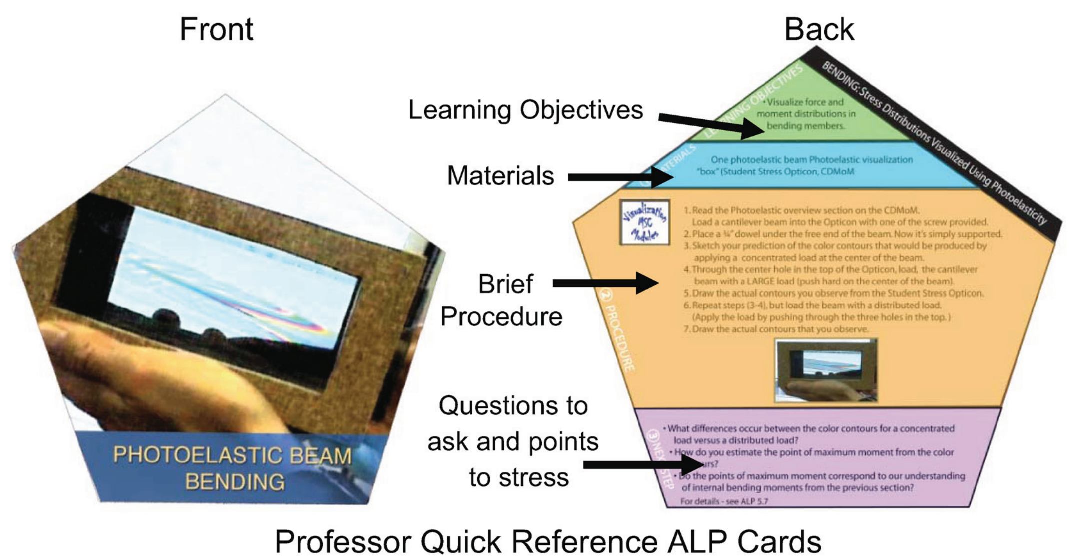


Figure 3. As a tool for implementation, each card provides a quick reference for preparing for class and while implementing an in-class activity.

The creation of the series of reference cards supplements the more detailed curriculum for the students and the professors (Figure 3). Each card is designed to be a quick review of the activity to assist a professor in preparing for class and during an in-class activity. Each card provides the learning objectives, the materials required, and an abbreviated procedure for activity implementation. The reference cards highlight salient points the professor may want to stress and suggested questions to ask.

4. EXAMPLE ACTIVITIES

The ALPs can be classified under five categories: Thought Experiments, Investigations, Hands-on, Multimedia, and Opportunities for Creativity. Most activities span more than one of the categories. Thought Experiments require the students to apply conceptual knowledge to a given situation and make a qualitative conclusion about the situation based on their conceptual understanding of the topic. Investigations ask the students to search for applications of the concepts and perform some basic engineering analysis. Hands-on activities involve the direct manipulation of physical demonstratives. Multimedia activities use the VisMOM software, a software package that presents interactive multimedia activities and overviews of basic mechanics of materials concepts. Activities with Opportunities for Creativity provide activities for small-scale design, curiosity, and improving innovation skills. The ALPs are intended as a more effective and efficient means to teach the important but difficult concepts. The following sections describe and give examples for each of the five categories of activities. Complete descriptions and all ALPs materials can be found at www.me.utexas.edu/~alps/.

4.1. Thought Experiments: Matching Loads and Failure Planes

Thought Experiment Activities ask the students to use a concept they have learned, apply it to a given situation, make a prediction, or answer a simple question. Many of the ALPs have aspects that are Thought Experiments and other aspects that are Hands-on. This approach allows a single ALP to meet the needs of students with different learning styles. Thought Experiments tend to bias toward reflective and intuitive learning styles whereas Hands-on tends to bias towards active and sensing learners. Within the Kolb model, Thought Experiments encourage reflective observation and abstract hypothesis & conceptualization.

One example activity in this category is the "Matching Loads and Failure Planes ALP" shown in Figure 4. For this activity, students apply their knowledge of loading conditions, maximum stress planes, and failure theories to correctly match the failure plane with the loading conditions. This activity has many possibilities for assignment context. It can be used as a quick in-class Think-Pair-Share activity

Loading Conditions:

1-Wind load, constant and horizontal

2-Skiing accident where a person fell and began to roll down the slope. The binding did not release so the skis did not follow the rolling motion of the skier.

3-Rock climbing injury. A large loose rock fell from above the climber and

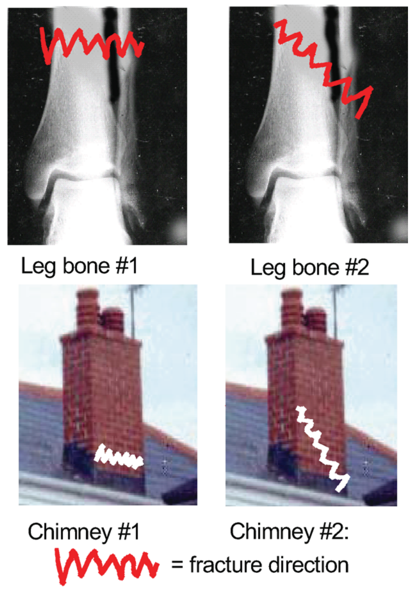


Figure 4. Example of a Thought Experiment Activity. Students match the loading conditions to the observed failure.

where the students first think about the problem for a couple of minutes, then turn to a partner and discuss it. This activity can naturally lead into a larger group discussion to provide ample opportunities for reinforcement of pertinent concepts, authentic situations for learning engineering vocabulary, and efficient assessment of learning. The flexibility of curriculum design allows the ALPs to fit into other contexts including, homework, a quick assessment, or as multiple choice exam questions.

4.2. Investigation Activities: Combined Loading

Investigation ALPs require the students to explore the world around them and find applications for the theories and concepts being taught. Theses ALPs typically require students to find examples where a given equation or theory applies in the real-world. Asking students to find real-world examples works well for most engineering concepts since it is an applied field. The Investigation ALPs are most effective if used as an individual or group homework and then a few minutes is spent in class reviewing the results.

An example Investigation ALP is the "Identify Items under Combined Loads ALP". Students identify everyday devices and structures that include combined loading. The students then complete a table of information including component, type of loading, and a free body diagram for each device (Table 3). Examples can be found for kitchen appliances, hand tools, power tools, children's toys,

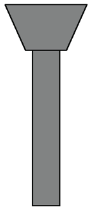
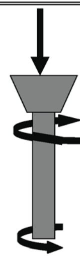
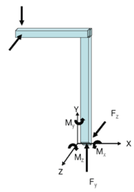
Device/ Structure	*Component*	*Type of Loads*	*FBD*
Screw while it is being driven into a piece of wood 	Screw 	Axial, Torsion	
Road Sign when the wind is blowing 	 Sign Post	Bending, Axial	

Table 3. Example of Combined Loads Worksheet.

sports equipment, homes, local bridges, and on the web. After the students complete the table as a homework, it is brought to class for group discussion.

This type of ALP helps students access the "concrete experience" step of the Kolb cycle and move toward the fourth (analysis), fifth (synthesis), and even possibly the sixth (evaluation) levels of the Bloom's taxonomy.

4.3. Hands-on ALPs: Brittle and Ductile Failure

Hands-on ALPs allow the students to directly manipulate physical materials to reinforce their learning. Hands-on experiences are concrete observations of mechanics of materials phenomena. Within the Kolb model, Hands-on ALPs tend to provide concrete experiences and active experimentation. Hands-on ALPs also support kinesthetic learning experiences. Some of the Hands-on ALPs also provide opportunities for reflective observation. Students who are sensors on the MBTI tend to respond very well to these hands-on experiences.

The "Brittle and Ductile Failure" ALP seeks to develop a deeper conceptual understanding of maximum stress planes and their relationship to the material type. Each student receives a piece of chalk and a Tootsie Roll. Each student twists the piece of chalk and a Tootsie Roll causing torsional failure (Figure 5). A second piece of chalk is broken using a bending load. The student compares the tactile and visual feedback to draw conclusions. The primary objective of this ALP is to help students understand stress transformations, basic failure theories and differences between brittle

Figure 5. Failure modes of chalk in torsion (top) and bending (bottom) and Tootsie Roll in torsion.

materials (like chalk) that fail due to normal stress and ductile materials (like Tootsie Rolls) that fail due to shear stress. In this light, students are asked to explain the angles on the failure surface and relate them to predicted failure modes with their associated failure planes. The fact that the brittle chalk fails at a 45° angle when in torsion allows the student to visually and tactilely correlate this angle with the maximum normal stress surface. The 90° failure surface for the ductile Tootsie Roll in torsion is seen to correlate with the maximum shear surface. The professor's role in this and the other ALPs is to guide the students through the activity, to provide feedback, and additional explanations as required. This activity is most effective as an in-class exercise guided by the professor.

4.4. Hands-on ALPs: Foam Rod

Another example of a Hands-on ALP is the "Combined Loading Foam Rod" ALP. It addresses the three educational objectives of: 1) understanding the differences between normal and shear stresses, 2) relating the different kinds of stress to different loading scenarios and 3) visualizing the stress distributions through the cross section of the rod. Students are given a section of a flexible foam rod (Figure 6). Pipe insulation is shown in the Figure 6, but other materials may also be used.

Pairs of students are instructed to manipulate the beam first in axial loading, then bending, then torsion, and then combinations of these loads as shown on the chart (Figure 7). Note that the chart the students received does not have the information in the last four columns filled in (Shape, σ_X (y/n), τ_{XY} (y/n) and Comments). One of the objectives of this activity is to provide students with tactile and visual information about the effects of different loading conditions. Therefore, it is critical that the students "feel" the type of loading that creates only normal stresses and simultaneously "see" that this does not cause angle changes in the stress elements. Alternately, they will "feel" the loading that causes shear stress and "see" that this loading does change the stress element angles from their original 90° values.

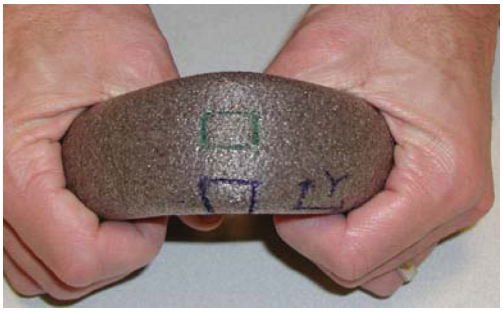


Figure 6. Foam Rod Deformation.

Point	Load Type	Shape	σ_x (y / n)	τ_{xy} (y / n)	Comments
Top (Red)	Axial	→ X	yes	no	P / A axial tensile (+) normal stress across entire cross section
Side (Blue)	Axial	→ X	yes	no	P / A axial tensile (+) normal stress across entire cross section
Bottom (Green)	Axial	→ X	yes	no	P / A axial tensile (+) normal stress across entire cross section
Top (Red)	Bending	→ X	yes	no	My / I bending tensile (+) normal stress from neutral axis up
Side (Blue)	Bending	→ x	no	yes	VQ / I T type shear stress is max at neutral axis and zero at the top and bottom of the cross section
Bottom (Green)	Bending	→ x	yes	no	My / I bending compressive (-) normal stress from neutral axis down
Top (Red)	Torsion	→ x	no	yes	Tr/J torsional shear stress on entire exterior surface of the rod
Side (Blue)	Torsion	→ x	no	yes	Tr/J torsional shear stress on entire exterior surface of the rod
Bottom (Green)	Torsion	→ x	no	yes	Tr/J torsional shear stress on entire exterior surface of the rod
Top (Red)	Torsion + Bending	→ x	yes	yes	My/I bending normal tensile stress + Tr/J torsional shear stress
Side (Blue)	Torsion + Bending	→ x	yes	yes	VQ/IT bending shear stress + Tr/J torsional shear stress
Bottom (Green)	Torsion + Bending	→ x	yes	yes	My/I bending compressive (-) normal stress + Tr/J torsional shear stress
Top (Red)	Axial + Bending	→ X	yes	no	My/I tensile bending normal stress + P/A axial tensile normal stress
Side (Blue)	Axial + Bending	→ x	yes	Yes	VQ/IT bending shear stress + P/A axial tensile normal stress
Bottom (Green)	Axial + Bending	→ x	yes	No	My/I compressive bending normal stress + P/A axial tensile normal stress (bending dominates)

Figure 7. Completed Chart from the Foam Rod ALP with additional comments.

4.5. Visual Mechanics of Materials Software: Design a Beam to Support a Traffic Light

Visual Mechanics of Materials (VisMOM) is a suite of interactive multimedia covering core concepts in a standard Mechanics of Materials course. It provides another avenue for students to learn. It is more visual than a traditional textbook. VisMOM contains hundreds of pictures, sketches, graphics, example problems, and design problems all geared toward providing a visually rich, interactive environment for students to experience Mechanics of Materials. The VisMOM software gives global overviews of the topics in each section, then provides students with example problems, and finally gives interactive visuals including design problems. The VisMOM software can be downloaded at www.me.utexas.edu/~alps/resources/index.php.

In the "Design a Beam to Support a Traffic Light" ALP, the students design a beam to support a traffic light taking into account minimizing cost, safety factors, beam weight, and stress in the beam. The exercise utilizes the VisMOM software to allow the students to interactively select material properties and cross-section geometry. The VisMOM software provides the students with the resulting model weight, safety factor, and cost (Figure 8). Multimedia applications tend to be particularly effective for visual learners and active learners. Multimedia allows active learners to quickly investigate a concept.

4.6. Opportunities for Creativity: Design and Manufacturing of Torsion Beams

Innovation in engineering is an important skill that young engineers receive little training in and few opportunities to sharpen this skill outside of their design classes. A number of the ALPs have innovation opportunities built into them. An example of this type of activity is the "Design and

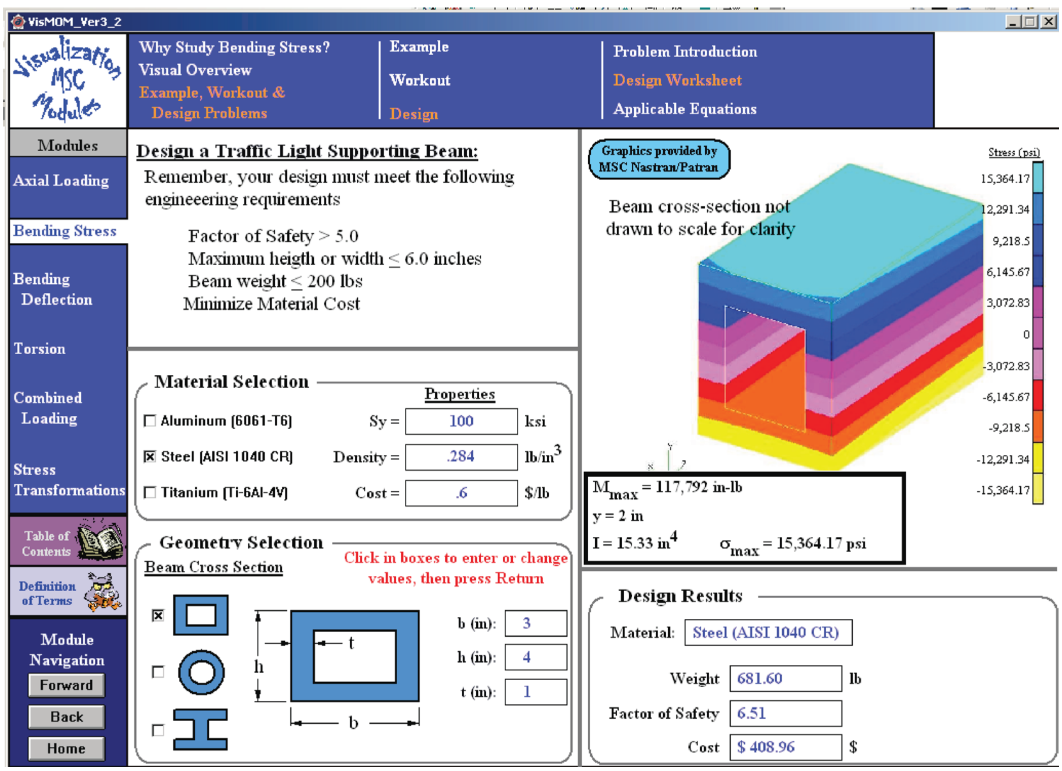


Figure 8. VisMOM- Design a Beam to Support a Traffic Light.

Manufacturing of Torsion Beams" ALP. This activity is a Hands-on ALP in which students experiment with the torsional stiffness of various cross-sections. Various beam cross-sections are built using Crayola Model Magic, a Playdough extruder, and thin sheets of plastic with custom extruder cross-sections. As a part of this activity, students must experiment with unusual and custom cross sections that they design. This can be extended to a mini competition by presenting the following scenario, "Design an aesthetically pleasing support beam." Table 4 shows the format used to capture the data from this ALP. Activities which support design and creativity reach the highest level of Bloom's taxonomy. The Opportunities for Creativity frequently force the students around the Kolb cycle. They require the students have concrete experiences building, actively experiment, reflect on failures, and to model their design to determine if it meets the objectives.

5. EXAMPLE ASSESSMENT RESULTS

The activities were evaluated at three different higher-education schools, a research institution, The University of Texas at Austin (UT), a primarily teaching institution, the United States Air Force Academy (USAFA) and a community college, Austin Community College (ACC). A combination of student opinion surveys, a concept inventory, pre/post activity quizzes and a focus group were used to evaluate the ALPs. In addition, students' personality types using Myers-Briggs Personality inventory

Cross section	**Prediction of relative torsional stiffness** >greater < less ≈ about the same	**Observed relative torsional stiffness**	**Cross-sectional Area (A)**	**Calculated Polar Moment of Inertia (J)**
Hexagon, solid circular, hollow circular cross-section 				
I-beam, wide web I-beam, square and hollow square cross-section 				Calculate J for only the square X-sections
Other Cross-sections/Design Competition				

Table 4. Cross-sections and relative torsional stiffness record.

[48–50], learning styles using the Felder-Soloman's Index of Learning Styles [46] and demographic information were also recorded and correlated with the other assessment information. In general, students were positive about the activities and felt their learning experience was improved. The activities are effective for a range of learning styles, personality types, and for a diverse community of learners. Measurable increases in learning as compared to a standard lecture are generally observed (Figure 9). Overall, evaluation of the ALPs shows they are an effective way to bring active learning into an engineering class and that they enhance learning [53].

Figure 9 shows an example result from the Foam Beam ALP. A short quiz was given before and after lecture to assess learning. The lecture with an ALP was compared to a traditional lecture without the ALP. The graph shows increased learning with the ALP. Students frequently have difficulty identifying the types of loads being applied to an object and the resulting stresses. The Foam Beam ALP was created to assist in overcoming these difficulties. As demonstrated by the pre/post quiz results, this has successfully been accomplished.

5.1. Effectiveness of the ALPs across Institution Types

One goal for the ALPs is that they be effective across a variety of institutions of higher learning. The ALPs have been tested at three institutions of higher learning. We use, as one measure, student survey data to help determine if their effectiveness is limited by institution type. As can be seen in Figure 10, data for a five question survey is shown for two types of institutions over three different semesters. The table represents data from approximately 150 students. Note that all of the responses are above at or above the "neutral" level of 3.0 and most are near the "agree." Overall,

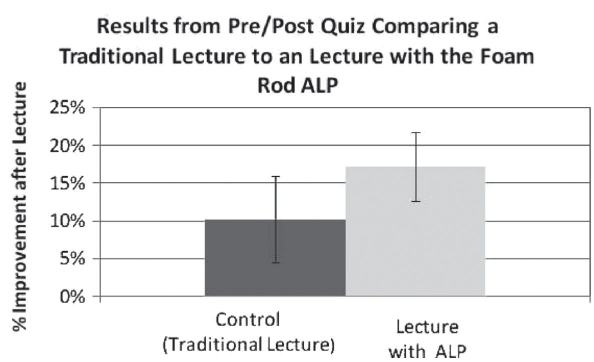


Figure 9. Pre/post lecture quiz results comparing learning from a traditional lecture to a lecture with the Foam Rod ALP (control group n = 62, ALP experimental group n = 91, n ≈ 20 per section, error bars are +/− one standard error).

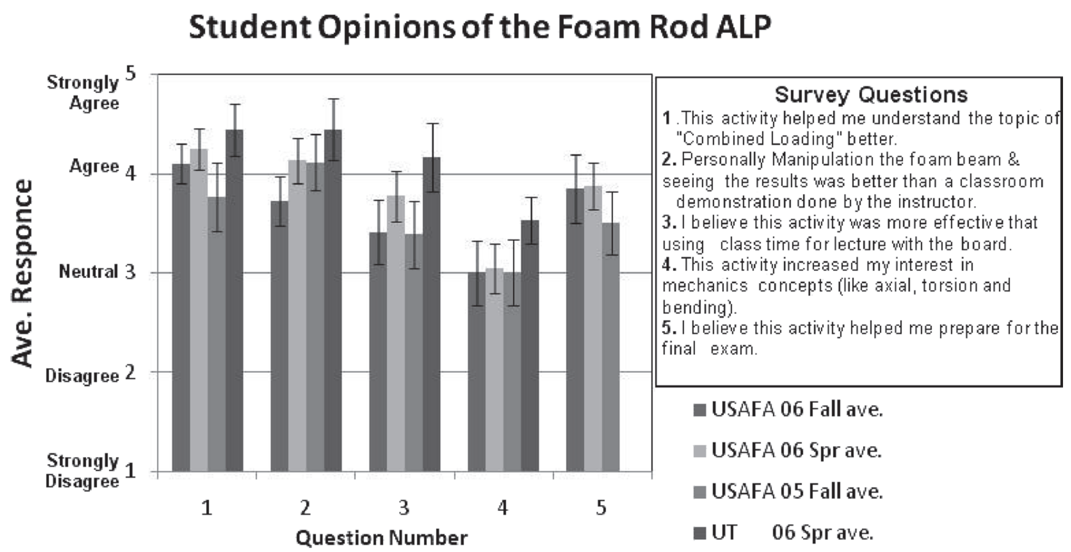


Figure 10. Student opinions of the Foam Rod ALP across institutions (n = 66, 77, 40, 25, respectively; error bars are +/− one standard error).

the University of Texas at Austin (UT) students evaluated the ALPs more positively than did the US Air Force Academy (USAFA). Students believed this activity increased their understanding of combined loading and it was an effective use of class time.

6. CONCLUSION AND FUTURE WORK

This paper describes the implementation and assessment results for a set of Active Learning Activities (ALPs) for use in mechanics classes. ALPs are an effective way to bring active learning into an engineering class and add a tremendously powerful tool to the engineering educator's tool chest. ALPs can be used to incorporate active learning into a traditional lecture with almost no overhead for the professor. The ALPs range from hands-on activities and thought experiments to multimedia software. A total of twenty-eight activities have been created. A complete description of all activities with student handouts and professor's notes can be found at www.me.utexas.edu/~alps/resources/index.php.

Future work will include continued improvements to developing, assessing, and implementing ALPs that improve the student learning process. ALPs will be created for other engineering topics and STEM classes. ALPs are shown to be effective for improving learning, students feel they are effective, and students desire more active learning activities in their classes. Future publications will include assessment results at three institutions of higher learning. Also, continued development and assessment of the PHLIpS Method (Producing Hands-on Learning to InsPire Students) for the creation of new ALPs will be completed.

ACKNOWLEDGEMENTS

This material is based upon work supported by the National Science Foundation under Grant No. DUE-0442614. Support is also acknowledged from University of Texas at Austin College of Engineering and the Cullen Trust Endowed Professorship in Engineering No. 1. and the Institute for Information and Technology Applications (IITA) at the US Air Force Academy. In addition, we acknowledge the support of the Department of Engineering Mechanics at the U.S. Air Force Academy as well as the financial support of the Dean's Assessment Funding Program. Any opinions, findings, or recommendations are those of the authors and do not necessarily reflect the views of the sponsors.

REFERENCES

[1] Prince, M. "Does active learning work? A review of the research." *Journal of Engineering Education* 93(3): 223–231, 2004. http://www.asee.org/publications/jee/PAPERS/display.cfm?pdf=800.pdf.

[2] Wood, K., Jensen, D., Linsey, J., and Schmidt, K. "Designing Active Learning Activities and Associated Assessment Plans." *NSF CCLI Conference Workshop*, 2008.

[3] National Research Council. *National science education standards*. www.sites.nationalacademies.org/nrc/index.htm (Accessed September 2008) 1999.

[4] National Research Council. *Environment and development: Sustainability science*, National Research Council Publication 292(5517): 641–642, 2000.

[5] Eisenhart, M., and Towne, L. "Contestation and change in national policy on "Scientifically Based." *Educational Researcher* 32(7): 31–38, 2003.

[6] National Research Council. *A handbook for teaching and learning in higher education: Enhancing academic practice* 2003.

[7] National Science Foundation. *Science and engineering indicators* 2000. http://www.nsf.gov/statistics/seind00/ (Accessed September 2008) 2000.

[8] National Science Foundation. *Knowledge dissemination and use in science and mathematics education: A literature review*. ERIC #ED363499 (Accessed September 2008) 1993.

[9] Shakerin, S., and Jensen, D.D. "Enhancement of mechanics education by means of photoelasticity and finite element method." *International Journal of Mechanical Engineering Education* 29(4): 307–320, 2001. http://www.lib.utexas.edu:2048/login?url=http://search.epnet.com/login.aspx?direct=true&db=aph&an=5916093

[10] Aglan, H.A., and Ali, S.F. "Hands-on experiences: An integral part of engineering curriculum reform." *Journal of Engineering Education* 85(4): 327–330, 1996. http://www.asee.org/publications/jee/PAPERS/display.cfm?pdf=132.pdf.

[11] Catalano, G.D., and Tonso, K.L. "The Sunrayce '95 idea: Adding hands-on design to an engineering curriculum." *Journal of Engineering Education:* 193–199, 1996. http://www.asee.org/publications/jee/PAPERS/display.cfm?pdf=519.pdf.

[12] Regan, M., and Sheppard, S. "Interactive multimedia courseware and the hands-on learning experience: An assessment." *Journal of Engineering Education:* 123–131, 1996. http://www.asee.org/publications/jee/PAPERS/display.cfm?pdf=157.pdf.

[13] Bonwell, C.C. "Active learning and learning styles." *Active Learning Workshops Conference, Content available at* http://www.active-learning-site.com/vark.htm, 1998.

[14] Kresta, S.M. "Hands-on demonstrations: An alternative to full scale lab experiments." *Journal of Engineering Education* 87(1): 7–9, 1998. http://www.asee.org/publications/jee/PAPERS/display.cfm?pdf=131.pdf.

[15] Jensen, D., and Bowe, M. "Hands-on experiences to enhance learning of design: Effectiveness in a reverse engineering/redesign context when correlated with MBTI and VARK types." *ASEE Annual Conference.* Charlotte, NC, 1999. http://soa.asee.org/paper/conference/paper-view.cfm?id=14314.

[16] Wood, J.J., and Wood, K.L. "The tinkerer's pendulum for machine system's education: Creating a basic hands-on environment with mechanical breadboards." *ASEE Annual Conference and Exposition*. St. Louis, MO, 2000. http://soa.asee.org/paper/conference/paper-view.cfm?id=15387.

[17] Bridge, J. "Incorporating active learning in an engineering materials science course." *ASEE Annual Conference and Exposition* 2001. http://soa.asee.org/paper/conference/paper-view.cfm?id=15979.

[18] Ditcher, A. "Effective teaching and learning in higher education, with particular reference to the undergraduate education of profession engineers." *International Journal of Engineering Education* 17(1): 24–29, 2001.

[19] Feland, J.M., and Fisher, C.A. "Cramming twenty pounds into a five-pound bag: Increasing curricular loads on design students and enjoying it!." *ASEE Annual Conference and Exposition*. Montreal, Quebec, Canada, 2002. http://soa.asee.org/paper/conference/paper-view.cfm?id=17037.

[20] Roselli, R., and Brophy, S. "Effectiveness of challenge-based instruction in biomechanics." *Journal of Engineering Education* 95(4): 311–324, 2006. http://www.asee.org/publications/jee/PAPERS/display.cfm?pdf=917.pdf.

[21] Wood, K.L., Jensen, D.D., Bezdek, J., and Otto, K. "Reverse engineering and redesign: Courses to incrementally and systematically teach design." *Journal of Engineering Education* 90(3): 363–374, 2001. http://www.asee.org/publications/jee/PAPERS/display.cfm?pdf=395.pdf.

[22] Felder, R. "Beating the numbers game: Effective teaching in large classes." *American Society of Engineering Education Annual Conference*, 1997. http://soa.asee.org/paper/conference/paper-view.cfm?id=13043.

[23] Wolfman, S.A. "Making lemonade: Exploring the bright side of large lecture courses." *SIGCSE 2002*: 2002.

[24] Adhikari, A., and Nolan, D. "But what good came of it as last? How to assess the value of undergraduate research." *Notes of the AMS* 49(10): 1252–1258, 2002.

[25] Barlow, and Villarejo. "Making a difference for minorities: Evaluation of an educational enrichment program." *Journal of Research in Science Teaching* 41(9): 861–881, 2004.

[26] Hathaway, R., Nagda, B., and Gregerman, S. "The relationship of undergraduate research participation to graduate and professional education pursuit: An empirical study." *Journal of College Student Development* 43(5): 614–631, 2002.

[27] Nagda, B., Gregerman, S., Jonides, J., and Von Hippel, W. "Undergraduate student-faculty partnerships affect student retention." *Review of Higher Education* 22(1): 55–72, 1998.

[28] Agogino, A., and Shi, S. "Scaffolding knowledge integration through designing multimedia case studies of engineering design." *ASEE Frontiers in Education Conference*. Atlanta, GA: 1995.

[29] Linn, M.C. "Designing computer learning environments for engineering and computer science: Scaffolded knowledge integration framework." *Journal of Science Education and Technology* 4(2): 103–126, 1995.

[30] Prince, M., and Felder, R. "Inductive teaching and learning methods: Definitions, comparisons, and research bases." *Journal of Engineering Education* 95(2): 123–138, 2006. http://www.asee.org/publications/jee/PAPERS/display.cfm?pdf=896.pdf.

[31] Kolb, D.A. *Experiential Learning: Experience as the Source of Learning and Development*, Englewood Cliffs, NJ: Prentice Hall, 1984.

[32] Felder, R. "Matters of Style." *ASEE Prism* 6(4): 18–23, 1996.

[33] Stice, J.E. "Using Kolb's learning cycle to improve student learning." *Journal of Engineering Education* 77(5): 291–296, 1987.

[34] Jensen, D., Wood, K., and Wood, J. "Enhancing mechanical engineering curriculum through the use of hands-on activities, interactive multimedia and tools to improve team dynamics." *International Journal of Engineering Education* 19(6): 874–884, 2003.

[35] Mayer, R.E. "Using illustrations to promote constructivist learning from science text." *Psychology of science text comprehension*: Lawrence Erlbaum Associates, Publishers, 2002, pp. 333–356.

[36] Narayanan, N.H., and Hegarty, M. "Multimedia design for communication of dynamic information." *International Journal of Human-Computer Studies* 57: 279–315, 2002.

[37] Krathwohl, D.R., Bloom, B.S., and Maisa, B.B. "Taxonomy of educational objectives: The classification of educational goals." *Handbook II, Affective Domain*, New York: David McKay Co. Inc., 1964.

[38] Hanson, J., and Sinclair, K. "Social constructivist teaching methods in Australian universities—reported uptake and perceived learning effects: A survey of lecturers." *Higher Education Research & Development* 27(3): 169–186, 2008.

[39] Marland, M., and Barnes, D. "Language across the curriculum: The implementation of the Bullock Report in the secondary school." *Trends in Education* 4(55), 1977.

[40] Bereiter, C., and Scardamalia, M. "Commentary of Part I: Process and product in problem-based learning." *Problem-based learning: A research perspective on learning interactions*: L. Erlbaum Associates, 2000.

[41] Palincsar, A. "Keeping the metaphor of scaffolding fresh: A response to C. Addison Stone's "The metaphor of scaffolding: It's utility for the field of learning disabilities." *Journal of Learning Disabilities* 31(4): 370–373, 1998.

[42] Brown, A., and Palincsar, A. "Reciprocal teaching of comprehension—fostering and comprehension—monitoring activities." *Cognition and Instruction* 1(2): 117–175, 1984.

[43] Piaget, J. "Science of education and the psychology of the child." *The British Journal of Educational Psychology* 43: 103–104, 1977.

[44] Lave, J., and Wenger, E. *Situated learning: Legitimate peripheral participation*, Boston: Cambridge University Press, 1991.

[45] Wenger, E. "Communities of practice: Learning as a social system." *Systems Thinker* 9(5): 1–10, 1998.

[46] Felder, R.M., and Soloman, B.A. *Index of learning styles*. http://www.ncsu.edu/felder-public/ILSpage.html (Accessed January 2007).

[47] Litzinger, T.A., Lee, S.H., Wise, J.C., and Felder, R.M. "A psychometric study of the index of learning styles." *Journal of Engineering Education* 96(4): 309–319, 2007.

[48] Jung, C.G. *Psychological Types, Volume 6 of the Collected Works of C.G. Jung (Original work published in 1921)*: Princeton University Press, 1971.

[49] Kersey, D., and Bates, M. *Please Understand Me*, Del Mar: Prometheus Press, 1984.

[50] McCaulley, M.H. "The MBTI and individual pathways in engineering design." *Journal of Engineering Education* 80(July/Aug): 537–542, 1990.

[51] Jensen, D., Wood, J., and Wood, K. "A design methodology for hands-on classroom experiences." *ASEE Annual Conference and Exposition*, 2004. http://soa.asee.org/paper/conference/paper-view.cfm?id=19604.

[52] Linsey, J., Cobb, B., Jensen, D., Wood, K., and Eways, S. "Methodology and tools for developing hands-on active learning activities." *American Society for Engineering Education Annual Conference*. Chicago, IL, 2006. http://soa.asee.org/paper/conference/paper-view.cfm?id=1534.

[53] Linsey, J., Talley, A., Jensen, D., Wood, K., Schmidt, K., Kuhr, R., and Eways, S. "From tootsie rolls to composites: Assessing a spectrum of active learning activities in engineering mechanics." *American Society for Engineering Education Annual Conference*. Honolulu, HI, 2007. http://soa.asee.org/paper/conference/paper-view.cfm?id=3726.

AUTHORS

Julie Linsey is an assistant professor in the Mechanical Engineering Department at Texas A&M University. Her research focus is on design methods, theory and engineering education with a particular focus on innovation and conceptual design. Contact: jlinsey@tamu.edu

Austin Talley is a graduate student in the Mechanical Engineering Department at The University of Texas at Austin. His research focus is in design methodology and engineering education. He received his B.S. from Texas A&M University and M.S.E. from The University of Texas at Austin. Contact: Austin@talleyweb.com.

Christina White is a doctoral candidate in the Curriculum and Teaching Department at Columbia University. Her research focus is in engineering education with particular emphasis in both engineering diversity and humanitarian design projects. She earned a M. Ed. from The University of Texas at Austin in Special Education. Contact: ckw.columbia@gmail.com

Dan Jensen is a Professor of Engineering Mechanics at the U.S. Air Force Academy. He received his B.S., M.S. and Ph.D. from the University of Colorado at Boulder. He has worked for Texas Instruments, Lockheed Martin, NASA, University of the Pacific, Lawrence Berkeley National Lab and MacNeal-Schwendler Corp. His research includes development of innovative design methodologies and enhancement of engineering education.

Kristin Wood is the Cullen Trust Endowed Professor in Engineering at The University of Texas at Austin, Department of Mechanical Engineering. Dr. Wood's current research interests focus on product design, development, and evolution. The current and near-future objective of this research is to develop design strategies, representations, and languages that will result in more comprehensive design tools, innovative manufacturing techniques, and design teaching aids at the college, pre-college, and industrial levels. Contact: wood@mail.utexas.edu