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From Tootsie Rolls to Composites: Assessing a Spectrum of Active Learning Activities in Engineering Mechanics

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Keywords: Active learning, hands-on activities, learning styles, Myers-Briggs

Abstract

The introduction of active learning exercises into a traditional lecture has been shown to improve student learning. Hands-on learning opportunities in labs and projects provide an additional approach in the active learning toolbox. This paper presents a series of innovative hands-on active learning activities for mechanics of materials topics. These activities are based on a *Methodology for Developing Hands-on Active Learning Activities*, a systematic approach for efficient and effective activity development, and were robustly evaluated at three institutions of higher learning. These institutions include a research university, a four-year primarily teaching institution and a community college. Seven of the twenty-eight activities have been rigorously evaluated to date. Evaluation consisted of a variety of measures, including student opinion surveys, focus groups, pre/post activity quizzes, exam questions and a concept inventory. In addition, demographic information, student learning styles and Myers-Briggs Personality were measured and are correlated to the student evaluation measures. Data from over 150 students is summarized and insights gained are discussed. In general, students are excited about the hands-on activities in lecture, and they believe the activities enhance their learning. While these general findings exist, students' opinions of the activities do vary with learning styles, institutions and their general understanding in the course. Learning styles, personality type, and perception of performance in the class all have influence on the students' opinions of the activities and will be measured further in future activity development and evaluation.

1. Introduction and Motivation

Active learning approaches improve students' overall learning1. There is considerable literature that addresses the advantages of using hands-on experiences in an engineering curriculum2,3,4,5,6,7,8,9,10,11,12,13,14,15. Although the importance of active learning activities is well recognized, little formal guidance in a systematic approach for development exists16. Many experts believe that a systematic approach for research in how we educate engineers is needed to provide a way to achieve long-lasting improvement in engineering education17,18,19. This paper presents findings from assessment of the application of Active Learning Products (ALPs) at multiple higher education academic institutions. ALPs are activities, such as hands-on exercises, thought experiments, forensic investigations, physical measurements, multimedia exercises, and design applications, that enhance student learning across learning styles and personality types. In this context, we seek to answer the following **educational research questions:**

- Question 1: What measures should be used to evaluate ALPs?
- Question 2: Are ALPs an effective approach for introducing active learning into a mechanics of materials (MoM) class? Do the ALPs enhance the learning process? What do the students think of the ALPs?
- Question 3: How are the effects of the ALPs different based on students' learning styles, personalities and demographics? How do the results vary across different institutions, professors and sections of a class?

This paper begins with a brief overview of the methodology used to develop the ALPs. Next details of the assessment methods used to analyze student learning are discussed. Then descriptions of the ALPs are presented. The full set of all materials for ALPs, created as part of the project, are available at the website http://www.me.utexas.edu/~mechmat/. The evaluation results from Austin Community College (ACC), the US Air Force Academy (USAFA), and University of Texas at Austin (UT) show students believe these activities are improving how they learn. We end our discussion with an eye toward the future of ALPs, in mechanics of materials and beyond.

2. Innovative Mechanics of Materials Activities

The activities evaluated are Active Learning Products (ALPs) developed to improve student's ability to understand mechanics of materials concepts. ALPs are based on enhancing learning through the use of hands-on and student-driven learning experiences. Figure 1 shows a concise methodology to efficiently guide the development ALPs20. The Active Learning Product Design Methodology was used for the development of many of ALPs for mechanics of materials and can be used for ALPs for any technical topic. The methodology begins with understanding education goals, followed by implementation of the education goals, generating ideas, systematically selection of the ideas, and evaluation of the ALP created (Figure 1). This methodology also seeks to address varied student personality types and learning styles. ALPs are thus categorized into strategic themes, such as hands-on exercises, thought experiments, forensic investigations, physical measurements, multimedia exercises, and design applications. Currently, twenty-eight ALPs for mechanics of materials have been created across these themes. The seven ALP evaluated in this paper are described in the following sections, 2.1 and 2.2, and focus on the themes of hands-on and multimedia exercises. A complete set of ALP materials including student worksheets, detailed professor notes and supporting material, are available at the Active Learning for Mechanics of Materials website (http://www.me.utexas.edu/~mechmat/).

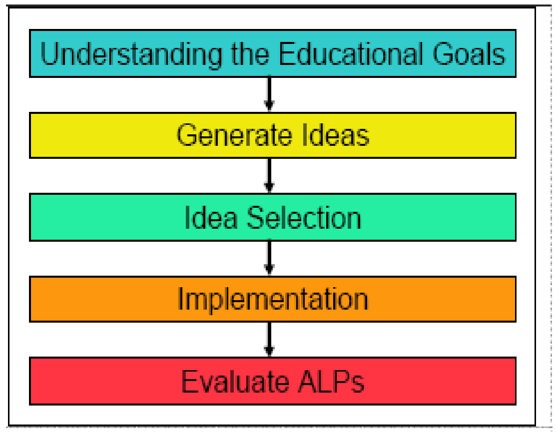


Figure 1: Active Learning Product Design Methodology

2.1. Exemplary Hands-on ALPs

2.1.1. Brittle and Ductile Failure

The "Brittle and Ductile Failure" ALP seeks to develop a deeper conceptual understanding of maximum stress planes, failure and their relationship to the material type. Each student receives a piece of chalk and two Tootsie Rolls. Each student twists the piece of chalk and a Tootsie Roll causing torsional failure (Figure 2). An additional observation of the chalk failing due to a bending load is made. The student compares the tactile and visual feedback to draw conclusions. The primary focus of this ALP is to help students understand that brittle materials (like chalk) fail due to normal stress while ductile materials (like tootsie rolls) 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. 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. (See http://www.me.utexas.edu/~mechmant/ for a complete description of the ALP.)

Figure 2: Failure modes of chalk in torsion (top) and bending (bottom) and Tootsie Roll in torsion.

2.1.2. Directional Strength

The "Directional Strength" ALP guides the students in obtaining hands-on experiences in the directional nature of a material's strength and its effect on the observed failure plane. Students individually draw a square representing a stress element on two craft sticks. Next, the students load them to failure in two different ways shown in Figure 3, applying end moments by bending the stick by hand and applying a point load to a simply supported beam. Next, the stick is placed with supports parallel to the grain of the wood and again loaded to failure. The grain-directional nature of the properties of the wood can easily be felt as the fracture parallel to the grain is initiated with only a fraction of the force needed to initiate fracture across the grain.

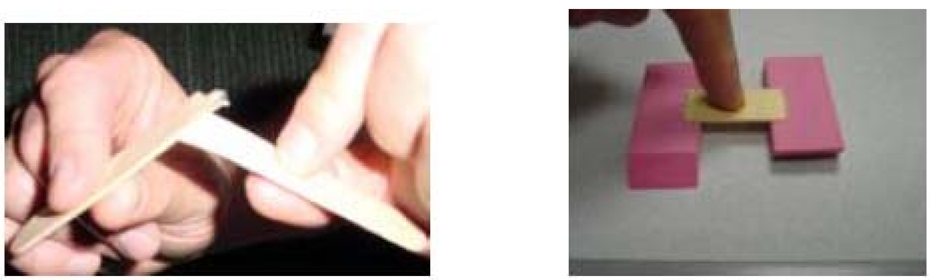


Figure 3: Loaded with end moments (left) and simply supported (right)

2.1.3. Foam Rod

The "Combined Loading Foam Rod" ALP was used at the US Air Force Academy during the Fall 2005 semester in two sections of the basic mechanics class. It may be helpful to understand that this course is not the standard Mechanics of Materials class. It is a "core" class, meaning that all cadets, including non-engineers, at the Academy are required to take the course. The content is a combination of statics and mechanics of materials, but is taught at a very basic level. The topic being covered was combined loading. In this context, the stakeholders the (instructors and cadets) both indicated that ALPs should be developed with the idea of exemplifying the basic conceptual content. This topic included understanding the differences between normal and shear stresses, relating the different kinds of stress to different loading scenarios and visualizing the stress distributions through the cross section of the

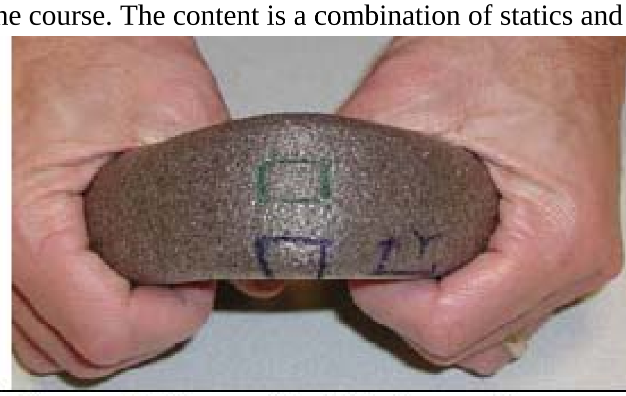


Figure 4: Foam Rod Deformation

rod. The following ALP was created to assist students visually and tactilely experience these three concepts.

Students were given a section of a flexible foam rod (see Figure 4). Pipe insulation was used for this class, however a "swimming pool noodle" could also be used. Each rod was approximately 10 inches long, with an outside diameter of 1.5 inches, and had three squares inscribed on its surface. In addition an axis was visible next to the blue square showing that the X-axis is located down the long axis of the rod.

A pair of students was instructed to manipulate the beam first in axial loading, then bending, then torsion and then combinations of these loads as shown on the chart (see Figure 5). Note that the chart that the students received did not have the information in the last 4 columns (Shape, *X* σ (y / n), *XY* τ (y / n) and Comments) filled in. The students were instructed to fill in that data. The purpose of the activity is to provide students with tactile and visual information on what types of loading (and combinations of loading) create certain deformations of the stress elements. It is critical, for example, that the students see that loading that creates only normal stresses does not cause angle changes in the stress elements, but loading that causes shear stress does change the stress element angels from their original 90^0 values.

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 5: Completed Chart from the Foam Rod ALP

2.1.4. Photoelastic Beam Bending

The "Visualizing Stress Distributions in Photoelastic Beam Bending" ALP allows the student to explore, through visual and tactile feedback, different factors that affect bending stress and the internal stress states in bending members. This activity is an in-class ALP with groups of two to four students. The photo elastic box, shown in Figure 6, is made of simple wood chipboard with a metal retention bracket, polycarbonate plastic beam, and two circular polarized lenses to make the stress in the beam visible. Student attempt to predict what color

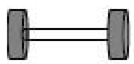
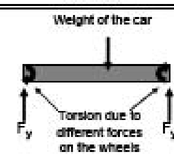
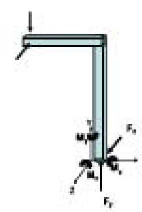
Figure 6: Loaded photoelastic beam

contours will occur for a cantilever photoelastic beam under light and heavy transverse loads. The students then bend the beams, observe the color contours, and compare them to their predictions. The color contours help students visualize the neutral axis as well as the moment distributions for the cantilevered bending problem.

2.1.5. Identify Items under Combined Loads

The "Identify Items under Combined Loads" ALP allows the student to obtain concrete experiences with everyday devices and structures that include combined loading. This ALP was suggested as an individual home work assignment. The student identified everyday devices and structures that have combined loads applied to them. The students then completed a table of information including component, type of loading, support model, and free body diagram for each item shown in Table 1. Examples are found in kitchen appliances, hand tools, power tools, children's toys, sports equipment, homes, local bridges and more. The students them complete the table for the items they have found and bring it back to class for group discussion.

Table 1: Example of Combined Loading Worksheet

Device/ Structure	*Component*	*Type of Loads*	*FBD*
Car 	Axial of a Car 	Bending, Torsion	
Road Sign when the wind is blowing 	Sign Post 	Bending, Axial	

2.2. Exemplary Visual Mechanics of Materials (Multimedia)

2.2.1. VisMOM Bending and Combined Loading Modules

The VisMOM modules on bending and combined loading provide students with a visual approach for teaching mechanics of materials rather than a more textually-biased approach that is typical of many textbooks (Figure 7 and Figure 8). The VisMOM software gives global overviews of the topics in each section and provides students with example problems and interactive visuals. The VisMOM software can be downloaded at http://www.me.utexas.edu/~mechmat/software.htm. For this activity students were instructed to read and work through the bending and combined loading modules.

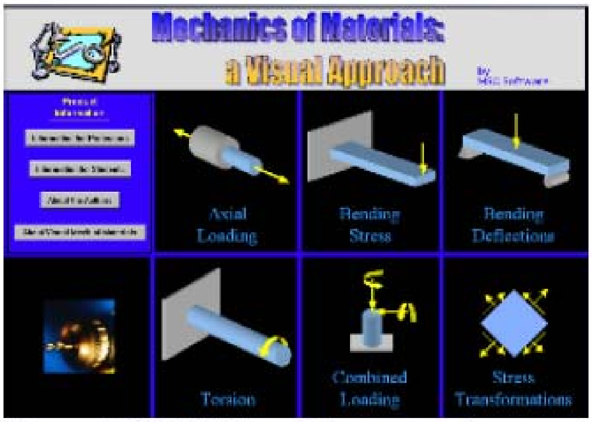


Figure 7: VisMOM modules, a visual approach to teaching mechanics of materials

Figure 8: Overview of a module's contents

2.2.2. VisMOM Traffic Light Beam Bending

In this ALP the students were asked in -groups to design a beam to support a traffic light. They were asked to take into account minimizing cost, safety factors, beam weight, and stress level in the beam. The exercise utilizes the Visual Mechanics of Materials (VisMOM) software to allow the students to interactively select material properties and cross section geometry. With the additional input of a Free Body Diagram and other information the VisMOM software provides the students with the resulting model weight, safety factor, and cost (Figure 9).

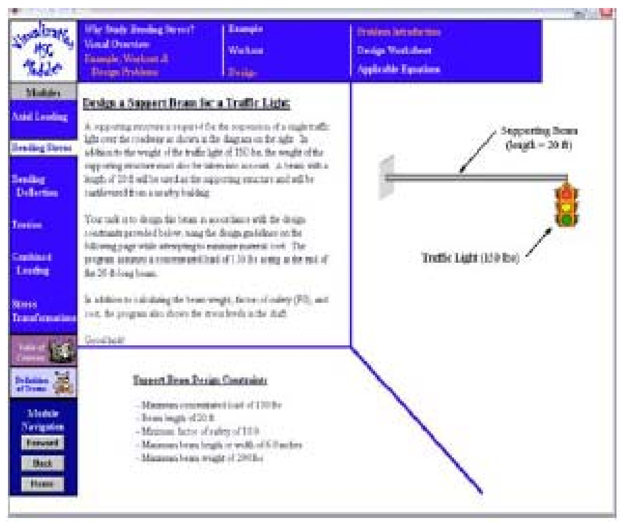


Figure 9: Traffic Light Beam Bending VisMOM

2.2.3. VisMOM Mohr's Circle

For this ALP, the VisMOM software creates an interactive Mohr's circle on a computer screen where the students can manipulate inputs and instantly see the effect on the stress planes. Students often feel intimidated by the creation of the Mohr's circle. This ALP allows the students to develop a feel for how Mohr's Circle can tell them stress planes in their application (Figure 10) as well as how the stress blocks, Mohr's circle and principle directions all relate.

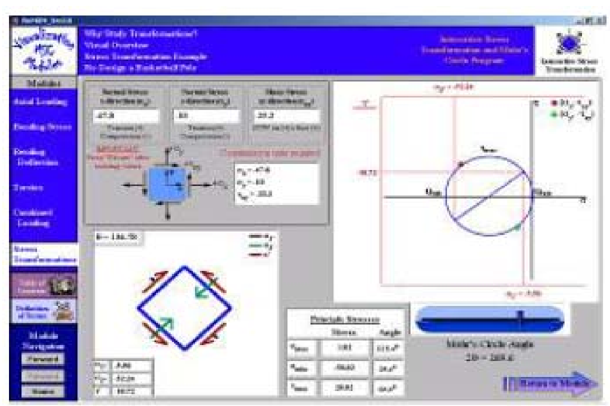


Figure 10: Mohr's Circle in VisMOM software

3. Method for the Evaluation of the ALPs

The evaluation of a total of seven of the twenty-eight created activities has taken place. The activities were evaluated at three different schools over four semesters. 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 inventory21,22,23, learning styles using the Felder-Soloman's Index of Learning Styles24 and demographic information was also recorded and correlated with the other assessment information. Demographic information included major, reason for taking the class, race, gender, G.P.A. and expected grade in the class. The students' expected grade was measured after approximately one month of class so this measure is an indication of how well the students felt they understood the initial material. Table 2 summarizes the activities that were evaluated and the measures used which are specific to each activity. Table 2 also shows measures across the activities including the demographics and learning styles. The following sections begin with a summary of the demographics, distribution of students' personality and learning styles and then show the assessment results for each activity.

Table 2: Overview of Activity Assessment

Semester	Fall 05		Spring 06		Sum 06	Fall 06
School	USAFA	ACC	UT	USAFA	UT	USAFA
Course	Machine Elements	Mechanics of Materials	Machine Elements	Basic Mechanics	Machine Elements	Mechanics of Materials
Activities and Topics			C, D, M, L, F	D, M, L, F	D, M, L, F	D, M, L, F
Bending-Flexure						
5.1 Internal Force & Moment						
5.1b VisMOM Traffic Light Beam Bending				S, D	Q, S, D	S, Q, D
5.2 Find items under bending						
5.3 Bending members with common cross-sections						
5.4 Feel craft sticks in bending						
5.5 Stress Opticon: Bending stress distribution				S, D		S, Q, D
5.6 Quantify flexure in a craft stick						
5.7 Stress Opticon: simple support						
Photoelastic beam bending						S, Q, D
Stress Transformation						
7.1 Directional Strength (Craft Stick)		S				
7.2 Directional Orientation in Structures						
7.3 Photoelasticity: Beam with holes						S, Q, D
7.4 Matching loads and failure planes						
7.5 Brittle and Ductile Failure		S	S, D		S, D	
7.6 VisMOM Mohr's Circle			S, D		S, D	S, Q, D
Combined Loading						
9.1 Identify items under combined loads				S, Q	S, Q, D	S, Q, D
9.2 Visualizing a stress element						
Foam rod	S		S, D	S, Q	S, Q, D	S, Q, D
9.3 Visualizing stress concentrations						
9.4 Observation of failure planes						
Foam beam and comparison chart						
VisMOM software Mohr's Circle			S			
Torsion						
1. Find components under torsion						
2. Design and Manufacturing of Torsion Beams						
Fatigue						
1. Find fatigue loads						
2. Fatigue failure of a wood beam						
3. Fatigue failure of an eraser						
4. Will the street signal pole fail?						

Legend: C=Pre/Post Concept Inventory, D=Activity Linked to Demographic Data, F=Focus Group, LS= Felder-Solomon's Index of Learning Styles, M=Myers-Briggs Personality Inventory, S=Survey, Q=Pre/Post Quiz

3.1. Myers-Briggs Type Indicator Personality Inventory

The Myers-Briggs Type Indicator (MBTI) includes four categories of preference21,22,23 (Table 3). Although MBTI categorization is well-established, its use as an indicator of the way people learn is far less common. The second of the four categories provides insight into how a person processes information. Those who prefer to use their five senses to process the information (sensors) are contrasted with those who view the intake of 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 in terms of implications for education8,15. One goal of the MBTI-based assessment is to determine if the ALPs favor one MBTI type over another. Ideally, the use of the ALPs would span the MBTI types without preference.

Table 3: Overview of MBTI

Manner in Which a Person Interacts With Others			
E	Focuses outwardly. Gains energy from others.	Focuses inwardly. Gains energy from cognition	**I**
EXTROVERSION		**INTROVERSION**	
Manner in Which a Person Processes Information			
S	Focus is on the five senses and experience.	Focus is on possibilities, use, big picture.	**N**
SENSING		**INTUITION**	
Manner in Which a Person Evaluates Information			
T	Focuses on objective facts and causes & effect.	Focuses on subjective meaning and values.	**F**
THINKING		**FEELING**	
Manner in Which a Person Comes to Conclusions			
J	Focus is on timely, planned decisions.	Focus on process oriented decision-making.	**P**
JUDGEMENT		**PERCEPTION**	

3.2. Felder-Soloman's Index of Learning Styles

Felders- Soloman's Index of Learning Styles24 are composed of four dimensions (active/reflective, sensing/intuitive, visual/verbal, and sequential/global) (Table 4). Richard M. Felder and Linda K. Silverman formulated this as a way of focusing on assessing the learning style of an individual. This index helps the instructor determine if an ALP has the same effect on all learning styles. As an example, instructors' teaching styles often favor sensing over intuitive learning styles or vice versa. The goal of this index is to assist instructors to create ALPs that impact all student learning styles equally.

Table 4: Felder-Soloman's Index of Learning Styles

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."

4. *Assessment Results*

The hands-on and VisMOM ALPs were implemented in the restructuring of traditional lecture classes at the three higher-education institutions over three semesters. Data has been collected and summarized. The results are extremely encouraging showing the students do learn more as compared with the traditional lecture, and they believe these activities are beneficial. The following sections show the assessment results first for the hands-on ALPs and then for the Multimedia ALPs. Direct assessment measures are shown first and then correlations between student feedback and the demographic data is displayed.

4.1. Hands-on

4.1.1. Results for Brittle and Ductile Failure ALP

The Brittle and Ductile Failure ALP was evaluated at ACC in the fall of 2005 with four students and at UT in Spring 2006 with twenty-seven students. At both schools, the students overwhelmingly expressed that the activity helped them to better understand brittle failure (Table 6, Figure 11). This result is encouraging, as brittle failure modes are known to be a difficult concept in VisMOM. In understanding ductile failure, students at UT also agreed that it helped them, but students at ACC were more mixed towards neutral regarding the utility of the activity. The ACC experimental population did have a small sample size, but this difference is worth investigating. Students at both schools were more neutral regarding their ability to draw stress elements after the activity. Positive signs for the activity were that the students at both schools thought the activity was worthwhile, would like to see more hands-on activities in class, and thought it was enjoyable.

Table 5: List of Survey Questions for Brittle and Ductile Failure Student Survey

1. This activity helped me to better understand brittle failure.
2. This activity helped me to better understand ductile failure.
3. The activity was a waste of time.
4.* The activity was NOT enjoyable.
5. I am better at drawing stress elements.
6. I would like more hands-on activities in class.

*Reversed Scored

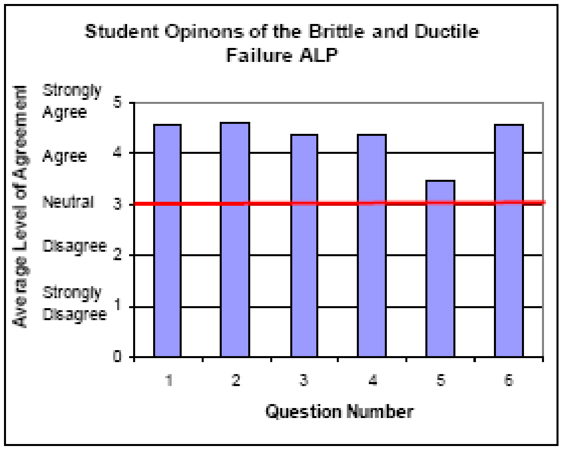


Figure 11: Brittle and Ductile Failure UT Spring 06

Table 6: ACC Fall 2005 Student Assessment of Brittle and Ductile Failure ALP

Question	Strongly Disagree	Disagree	Agree	Strongly Agree
This activity helped me to better understand brittle failure.	0	0	3	1
This activity helped me to better understand ductile failure.	0	2	1	1
The activity was a waste of time.	1	2	1	0
The activity was enjoyable.	1	0	2	1
I am better at drawing stress elements.	0	2	2	0
I would like more hands-on activities in class.	0	1	1	2

4.1.2. Results for Directional Strength ALP

The Directional Strength ALP was evaluated at ACC in fall of 2005 with five students. The students overall felt the activity helped them to understand the relationship between stress direction and failure along with material strength direction and failure (Table 7). Most of the students thought it was enjoyable and not a waste of time. The students felt the ALP improved their understanding of loading conditions. Overall, even with the small sample size, the students felt the ALP was positive and would like to see more hands-on activities in the future.

Table 7: ACC Fall 2005 Student Assessment of the Directional Strength ALP

Question	Strongly Disagree	Disagree	Agree	Strongly Agree
1. This activity helped me to better understand the relationship between stress direction and failure.	0	1	4	0
2. This activity helped me to better understand relationship between material strength direction and failure.	0	1	3	1
3. The activity was a waste of time.	1	3	1	0
4. The activity was enjoyable.	0	2	2	1
5. I am better at understanding loading conditions.	0	1	4	0
6. I would like more hands-on activities in class.	0	0	4	1

4.1.3. Results for Foam Rod Failure ALP

The Foam Rod Failure ALP was evaluated at UT in Spring 2006 with 25 students and at USAFA in Spring 2006 with 62 students in control sections and 91 students in experimental sections (Figure 12). USAFA students were given quizzes on combined loading before and after the lecture. The different bars on the Figure 13 graph represent different sections (3 control sections that did not have the active learning experience and 4 experimental sections that did have the active learning experience). As can be seen in the figure, students receiving the active learning activity showed a greater improvement in their quiz score as compared to those that did not have the active learning experience. Note that there is a significant variation in the quiz score improvement between the different sections of the course. The source of these variations remains an open research topic.

Figure 12:Foam Rod Failure

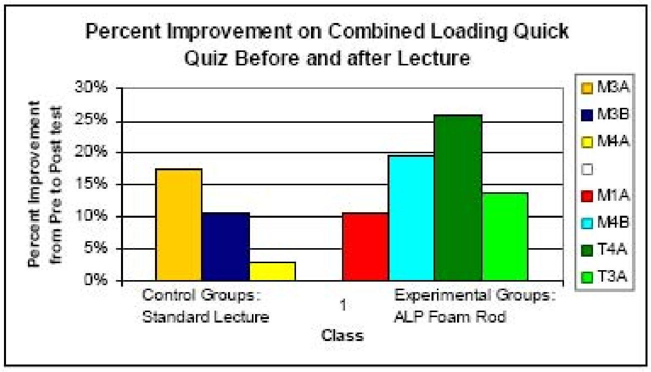


Figure 13: Percent Improvement by Class Section USAFA Spring 2006

4.1.3.1 <u>Foam Rod Survey Results</u>

From the student survey responses, all students felt that personally manipulating the foam beam and seeing the results was better than a classroom demonstration carried out by the instructor, indicating the students' preference for hands-on actives (Figure 14). The majority of the students did not feel that the activity increased their interest in mechanics concepts. Students at USAFA in the Fall 2005 and Spring 2006 semesters had similar scores between the semesters, but with a more skeptical response to the surveys than UT.

Overall UT students scored the surveys much higher in all categories. Figure 15 and Figure 16 break down question number one from Figure 14. This detailed snap shot shows the greater skepticism of USAFA students versus UT students. Although we do not know for sure, we hypothesize that the less enthusiastic response from the USAFA cadets may be due to the fact that the course where they experience the active learning is taken by all cadets regardless of major. Therefore, the majority of students in the class are not technical majors and thus may have a reduced interest in the content.

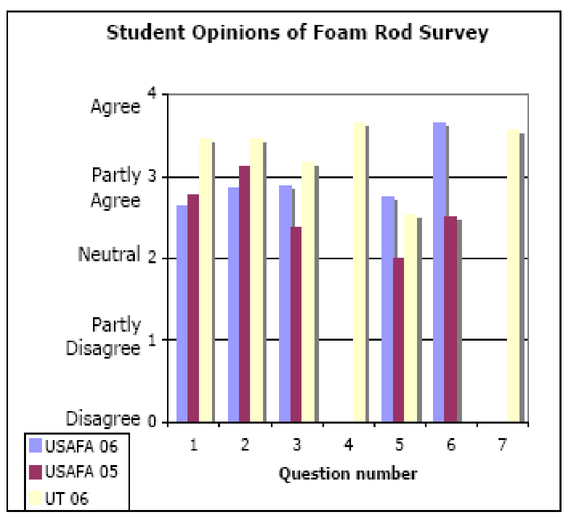


Figure 14: Foam Rod Survey Average Response USAFA Spr 06, Fall 05, & UT Spr 06

Table 8: Foam Rod Survey Questions

1	This activity helped me understand the topic of "Combined Loading" better.
2	Personally manipulating the foam beam & seeing the results was better than a classroom demonstration done by the instructor.
3	I believe this activity was more effective than using class time for lecture with the board.
4	The activity was a waste of time.
5	This activity increased my interest in mechanics concepts (like axial, torsion and bending).
6	I believe this activity helped me prepare for the final exam.
7	I liked doing this activity.

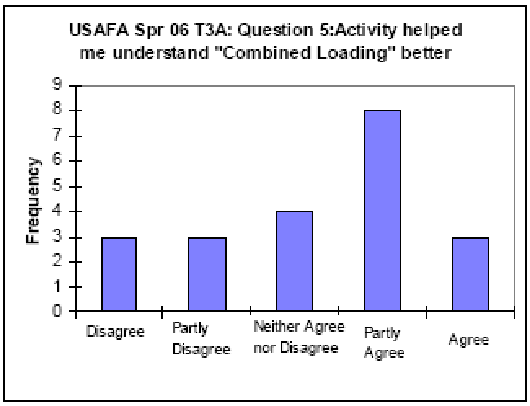


Figure 15: "This activity helped me understand combined loading better." USAFA Spr 06.

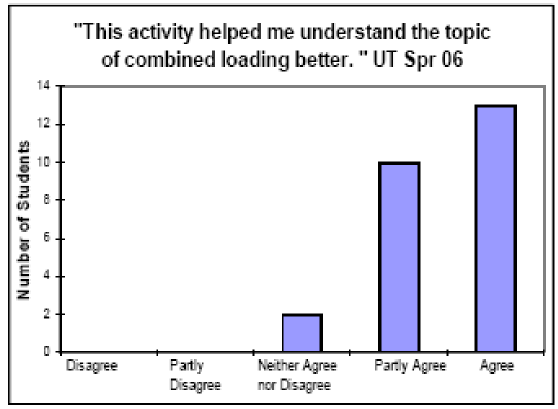


Figure 16: "This activity helped me understand combined loading better." UT Spr 06 T3A

4.1.4. Photoelastic Beam Bending

The photoelastic beam bending ALP was evaluated at USAFA in Spring 2006 with a total of 98 students across four class sections with three different professors. Each section had approximately 25 students. In general, students provided positive feedback about this activity (Figure 17 and Table 9). Most students liked executing the activity. They felt like it was a good use of their time and it improved their conceptual understanding of the topic. Students were indifferent if the activity would help them do better on homework or exams even though they felt this activity helped their conceptual understanding. Most students felt having the photoelastic devices in their hands was better than only watching a demonstration in front of the class.

Table 9: Survey Questions

1. This activity helped me understand the topic of "Bending" better.
2. Personally seeing/touching the photoelastic device was better than a classroom demonstration done by the instructor.
3. This activity will help me do bending homework problems.
4. This activity helped me understand bending in a conceptual manner.
5. This activity will help me on the next exam.
6.*****This activity was **NOT** confusing.
7. I believe this activity was more effective than using class time for lectures or boardwork.
8. *The activity was **NOT** a waste of time.
9. This activity increased my interest in mechanics concepts (like axial, torsion and bending).
10. I liked doing this activity.

*reverse scored

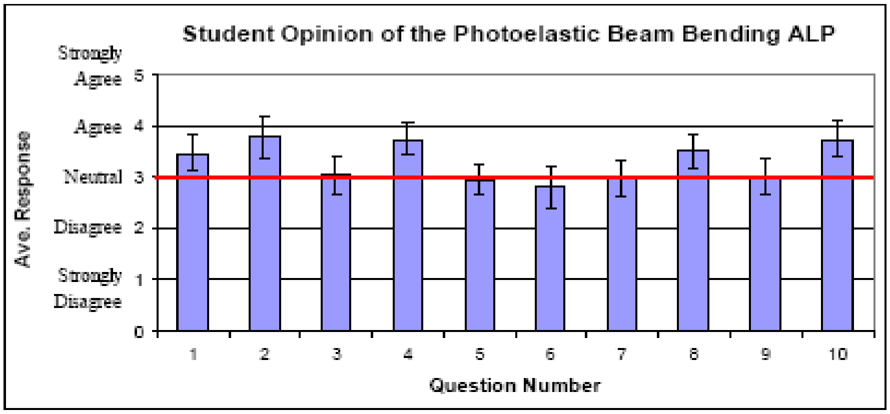


Figure 17: Student opinion of the photoelastic beam bending ALP. Each error bar is two standard errors.

There is also significant variation between sections, even two sections taught by the same professor (Figure 18). Some sections found the activity confusing. The only exception to this is the second section taught by the same professor. Understanding some of these details from the assessment will require additional iterations of the assessment plan.

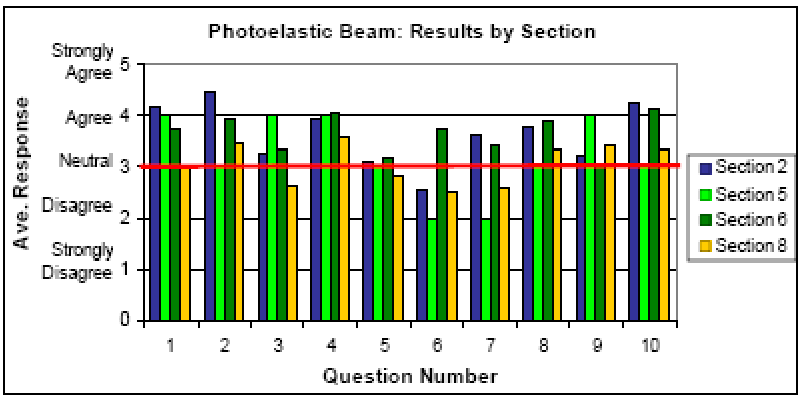


Figure 18: Student opinion of the photoelastic beam bending ALP by section (n≈25 per section).

4.1.4.1 Student Assessment Results Correlated with Demographics

The students' perception of their performance in class influenced their evaluation of the ALP. Demographic data, learning styles and personality was only correlated to some of the surveys. This information was correlated to the photoelastic beam and is presented here. In general, students who did not feel they understood the material as well (they expected to get a "C" in the course) generally rated this activity more positively than students who were expected "A's" in the class (Figure 19). Surprisingly students who were having more difficulties, actually enjoyed doing this activity more (Figure 19, question 10). No differences were observed with career plans after graduation or overall G.P.A.

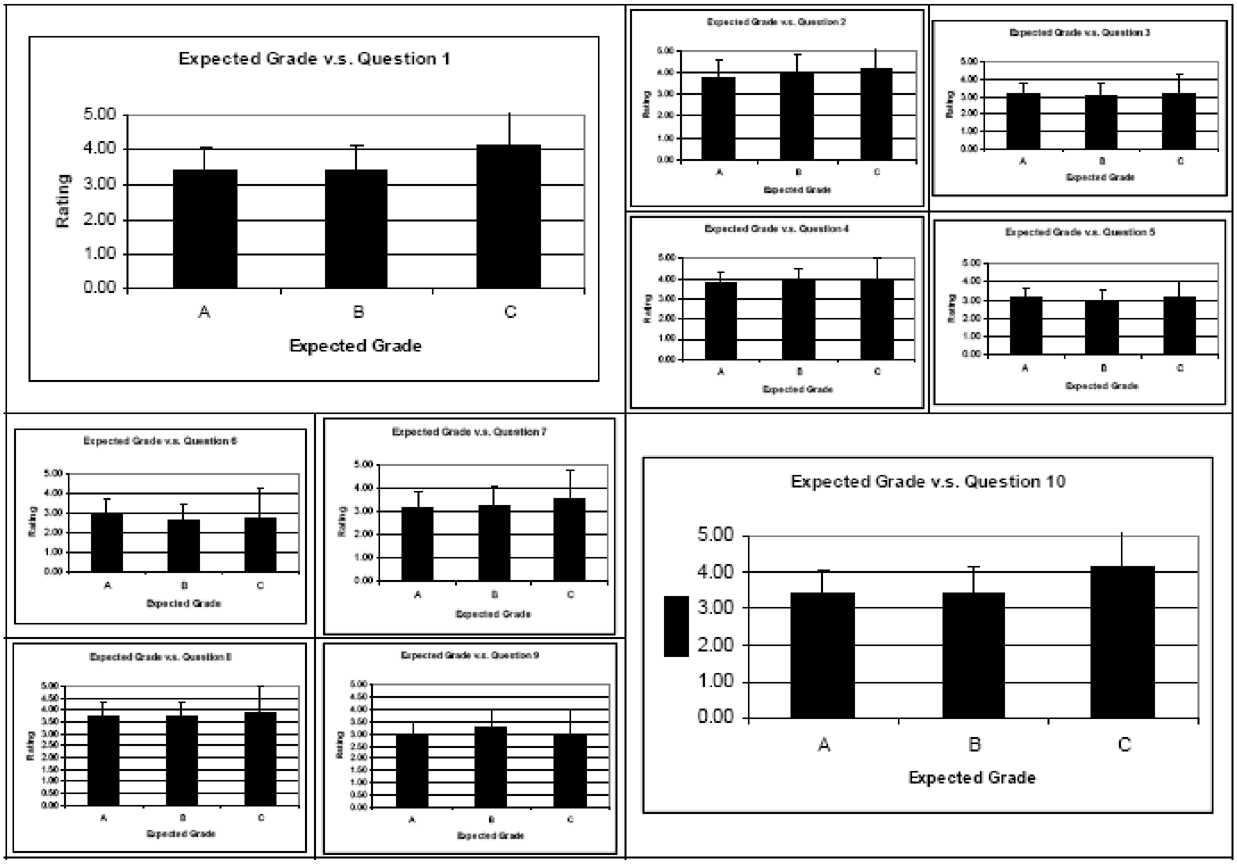


Figure 19: Students' understanding of the class, as measured by their expected grade, influenced their evaluation of the activities. (A: n= 28, B: n=21, C: n=8). Each error bar is two standard errors.

4.1.4.2 Student Assessment Results Correlated with Learning Styles

This ALPs was generally equally effective across the various learning styles. The only statistically significant differences were observed for global and sequential learners (Figure 20). As can be seen in Figure 20, sequential learners believed that the photoelastic beam bending activity would not help them with bending homework problems. Sequential learners were also more confused by the activity and were more likely to feel the activity was a waste of time. This is an unexpected result as the ALPs were designed to be implemented in a step by step fashion. We anticipated that this would facilitate the sequential learner over the global learner. Additional assessment is needed to discover the cause of this result.

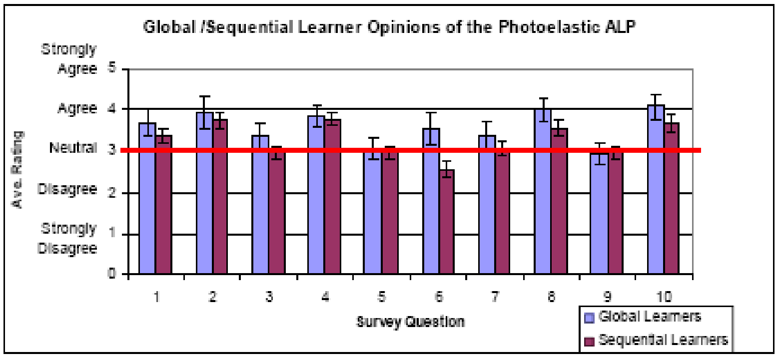


Figure 20: Influence of global and sequential learning styles on their opinions of the photoelastic beam ALP

4.1.4.3 Student Assessment Results Correlated with Personality Type

The photoelastic beam activity was completed in groups of two to four students and therefore it was not unexpected that extrovert students would be more positive about the activity than introverts. As can be seen in Figure 21, the assessment validates this hypothesis. Figure 22 shows that Intuitors found this activity more confusing than their Sensor counterparts, but were otherwise generally more positive about this activity. Perhaps the fact that this activity requires substantial reflective thought to connect the visual stress pattern information to the underlying phenomena explains the differences based on Sensor and Intuitor personality types.

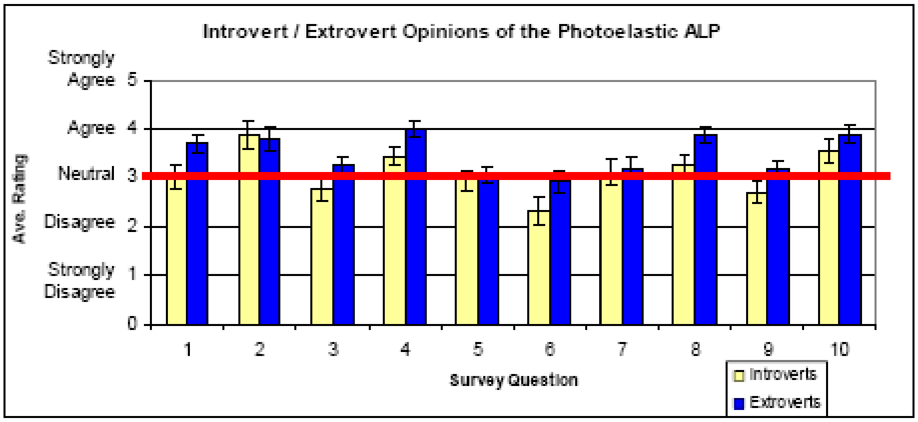


Figure 21: Extroverts were more positive about this group activity than introverts.

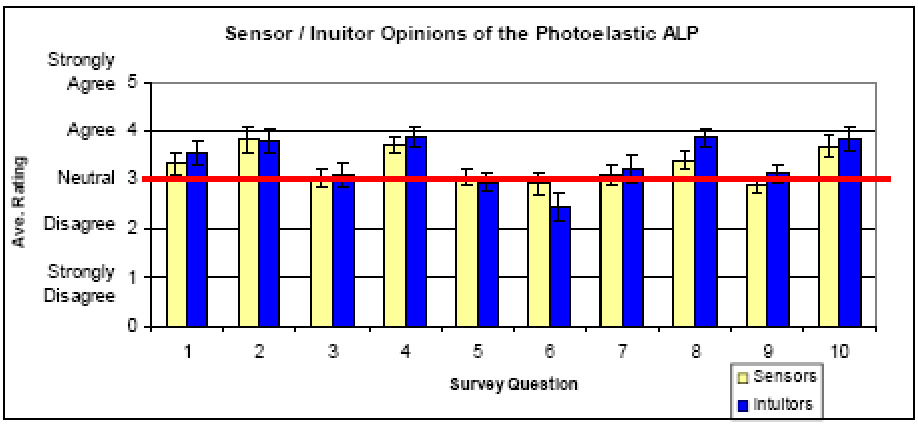


Figure 22: Students opinions did vary depending if they were sensors or intuitors.

4.1.5. Results Identify Items under Combined Loads ALP

Students at USAFA in the spring of 2006 in four sections were surveyed for their option of the “Identify Items Under Combined Loads” ALP. Overall, it can be seen in Figure 23 that there are significant differences in responses from the four different sections. The students seem ambivalent regarding whether the activity helped them understand combined loading better (question 1). They generally thought that the activity was preferable to only seeing an example in class and that it was more effective than a standard homework assignment (questions 2 & 3). However, the activity did not appear to increase their interest in mechanics and they were not convinced it would help them prepare for the exam (questions 4 & 5).

Table 10: List of Survey Questions for “Identify Items under Combined Loads” ALP

1. This investigation activity helped me understand the topic of “Combined Loading” better.
2. The investigation activity was preferable to only seeing examples in the text.
3. I believe this investigation activity was more effective than a standard homework assignment.
4. This investigation activity increased my interest in mechanics concepts (like axial, torsion and bending).
5. I believe this investigation activity helped me prepare for the final exam.

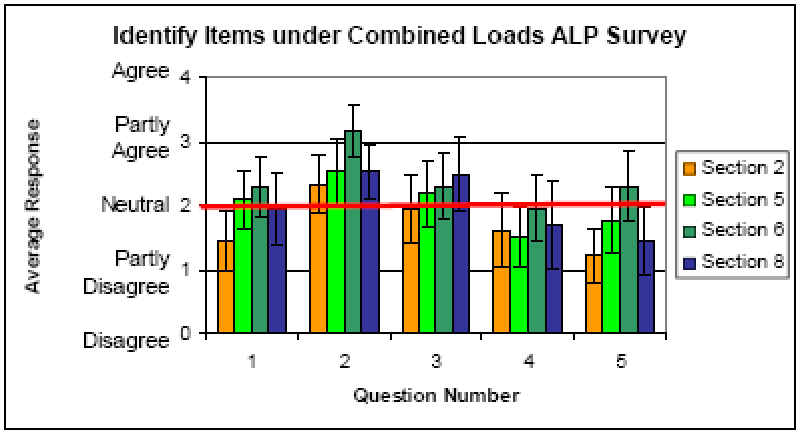


Figure 23: Student Opinions of the "Identify Items under Combined Loads" ALP by section. (Error bars are two standard errors. n=18, 22, 23, 21 and 20 respectively)

4.2. Visual Mechanics of Materials (Multimedia)

4.2.1. Assessment from the Interactive Multimedia VisMOM

One of the ways VisMOM has been assessed is through a student survey that requests a numerical response for each of seven questions (Table 11). An overview of the students' response is provided below. It is clear that the overall student assessment of VisMOM is very positive. The 90% rating (question 6) is particularly significant as historically it has been difficult to motivate the students to read the text. Students also provided written comments on VisMOM, noting specifically the easy navigation and helpful visualization. Others indicated that the active learning "has kept the class more interesting and increased my motivation".

Table 11: Student Response to VisMOM Survey

STATEMENT	Percentage of students rating either "3=Statement is mostly accurate" or "4=Statement is very accurate"
Q1: The courseware helped me understand the content.	79
Q2: The courseware motivated me to study this topic by showing me applications.	60
Q3: I believe the courseware would help me study for the exam.	83
Q4: The courseware made the lecture more interesting.	52
Q5: The courseware helped me visualize the basic mechanics.	83
Q6: I believe the courseware would be a good way to familiarize myself with the material BEFORE the lecture.	90
Q7: The interactive design problem was interesting and helpful.	69

SCALE: 0 = Statement is very inaccurate, 1 = Statement is mostly inaccurate, 2 = Statement is 50% accurate, 3 = Statement is mostly accurate, 4 = Statement is very accurate

Another form of assessment used for VisMOM was "Quick Quizzes" administered immediately before and again after VisMOM was used. The control group was formed by administering the same quick quiz before and after a classic lecture style class. The results tabulated in Table 12 were normalized to indicate the average score (percentage) achieved with and without the multimedia. Note that for each of the three VisMOM subjects, the students had greater quiz score improvement using the multimedia than they did from traditional lecture. This data is based on over 100 data points. Also, the same two professors were giving the traditional lectures as were using the VisMOM, which removes individual professor's effectiveness as a "noise" variable.

Table 12: Quick Quiz Results

VisMOM Subject	Description of the Group	Average Quiz Score Before	Average Quiz Score After	Percent Improvement
Torsion	Students who saw the module	80%	100%	20%
	Students who did NOT see the module	62%	71%	9%
Bending	Students who saw the module	27%	69%	42%
	Students who did NOT see the module	43%	76%	33%
Combine Loading	Students who saw the module	35%	93%	58%
	Students who did NOT see the module	21%	75%	54%

Finally, in an attempt to obtain a more longitudinal assessment of learning increases facilitated by VisMOM, a specific final exam question, which tested content covered either by VisMOM or by traditional lecture, was given. As shown in Table 13, the percentage of students who correctly answered the exam question was significantly greater (45%) for those who used VisMOM compared with those who did not (28%).

Table 13: Final Exam Results

	Number of Data Points	% of Students Correctly Answering the Exam Prob.
Students Receiving the Module	40	45%
Students NOT Receiving the Module	635	28%
Percent Difference		23%

4.2.2. VisMOM Traffic Light Beam Bending (Design a Beam to Support a Traffic Light)

Students at the USAFA in four sections with three different professors gave their opinions of the VisMOM traffic light ALP. In general students were indifferent or somewhat positive about the VisMOM Traffic Light ALP but there is significant variation in the data with students at both extremes. Students, in general, "partly agreed" that this ALP was not a waste of time. Most students do not plan to use the VisMOM software to help them with future homework problems. This activity did not increase their interest mechanics concepts. No large variations between the sections were observed. There are significant differences in students' opinions as moderated by demographics, learning styles and personality that are discussed in the following sections.

Table 14: List of Survey Questions

1. This activity helped me understand the topic of "Bending" better.
2. I plan to use the VisMOM software to help me study or do homework later in this course.
3. This activity will help me do future bending homework or exam problems.
4. This activity helped me understand bending in a conceptual manner.
5. This activity will help me on the next exam.
6*. This activity was NOT confusing.
7. I believe this activity was more effective than normal homework from the text.
8*. The activity was NOT a waste of time.
9. This activity increased my interest in mechanics concepts (like axial, torsion and bending).
10. I liked doing this activity.

*Reversed scored

4.2.2.1 Opinions as Moderated Demographics

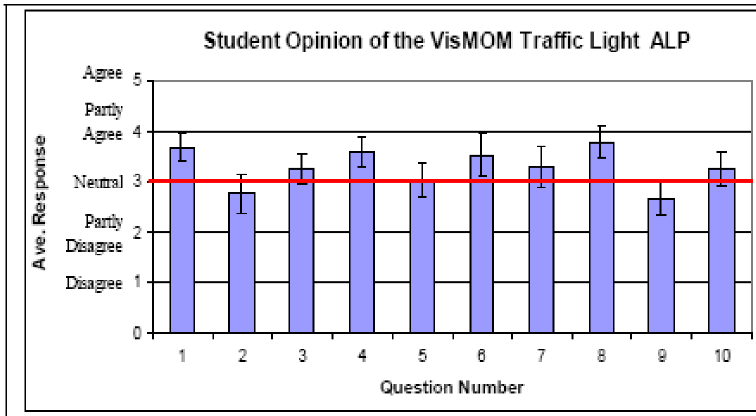


Figure 24: Student Opinion of the VisMOM Traffic Light (Error bars are two standard errors)

For the VisMOM traffic light, students' opinions were significantly different for some questions based on how well they felt they were doing in the class, as measured by expected grade (Figure 25,). There were no trends or significant differences based on the students GPA or their career plans. The students' expected grade was measured after approximately one month of class so this measure is an indication of how well the students felt they understood the material. Students doing well in the class generally rated this activity higher than students doing poorly. Students who were expecting to get an "A" were less confused about the activity than students who expected to get a "C". "A" student felt this activity improved their conceptual understanding more than the "B" students did.

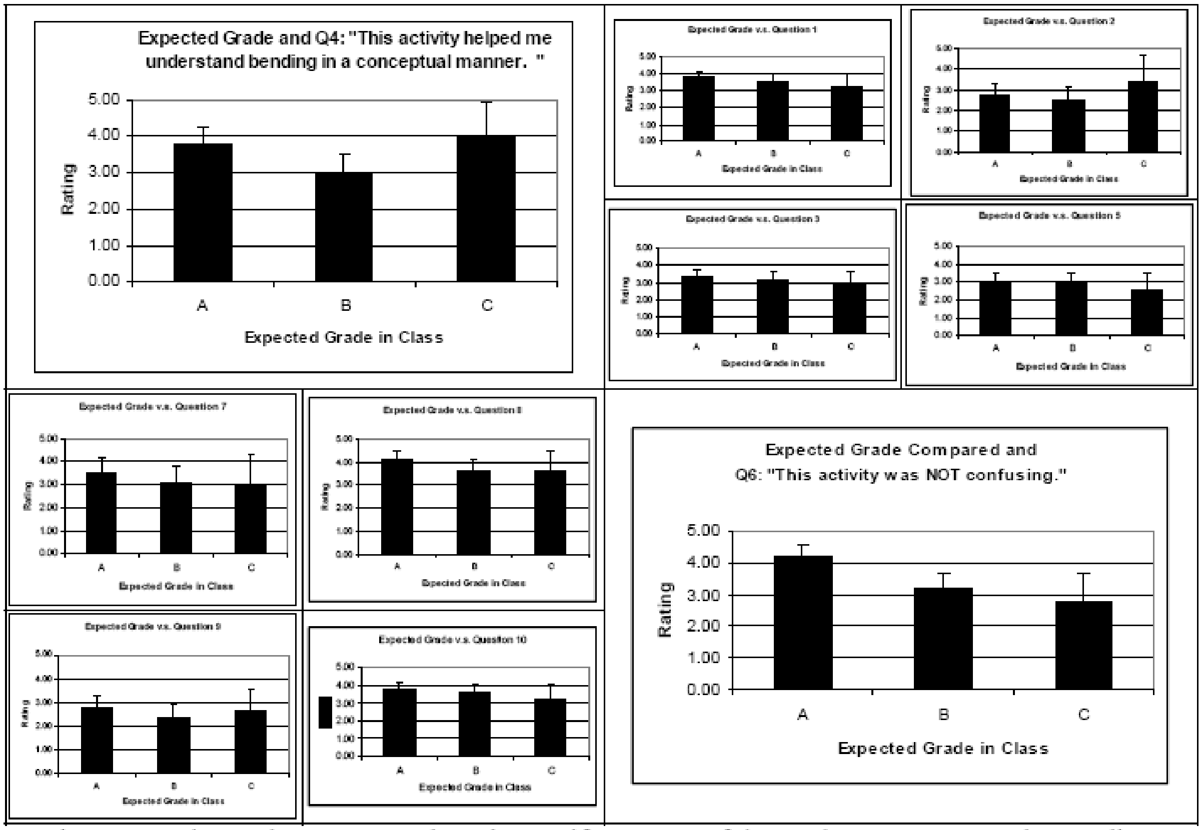


Figure 25: The students expected grade, a self-measure of the students' current understanding, influences the students' opinions of the activities.
(Error bars are 2 standard errors. A: n= 13, B: n=15 and C: n=4)

4.2.2.2 <u>Student Assessment Results Correlated with Learning Styles</u>

For many of the survey questions (Table 14) there were no significant differences based on learning styles. Active and reflective learners did have different opinions for a few of the survey questions (Figure 26). Reflective learners felt the VisMOM Traffic Light ALP would help them on their next exam, question 5 (t=2.15, p<0.05). Visual / verbal and intuitive / sensing learners also had varying views on a few of the questions (Figure 27 and Figure 28).

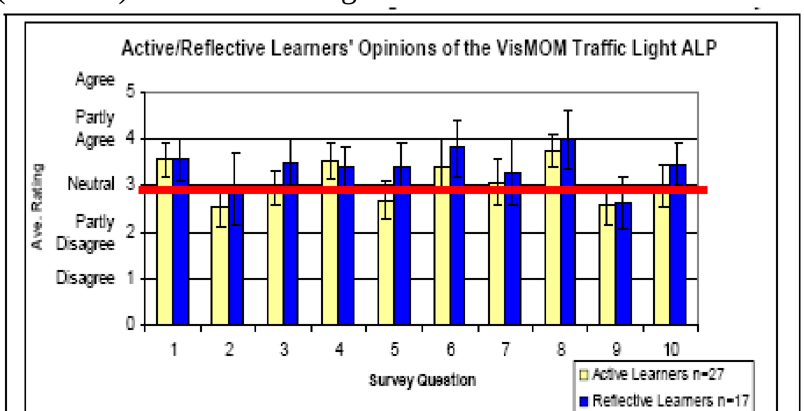


Figure 26: Comparison of active and reflective learners' opinions of the VisMOM traffic light ALP.

For the VisMOM traffic light ALP, intuitive and sensing learners' opinions did differ significantly on a few survey questions (Figure 27). Intuitive learners found this ALP much more effective for learning (question 7, t=3.65, p<0.05) and more useful than the sensing opinions of the VisMOM traffic light ALP.

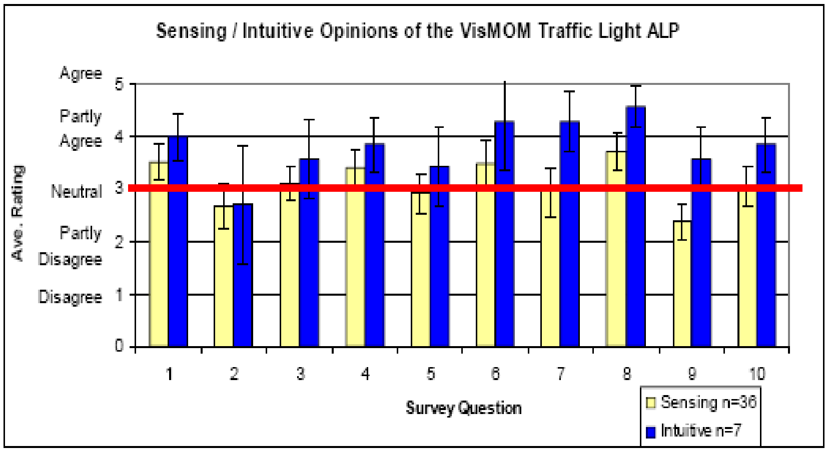


Figure 27: Comparison of sensor and intuitor learners' opinions of the VisMOM traffic light ALP. (Error bars are 2 standard errors)

In general visual learners were much more positive about the VisMOM traffic light ALP than verbal learners. This is not entirely surprising given the highly visual and interactive nature of this ALP. Visual learners felt that the VisMOM Traffic Light ALP increased their understanding more than the verbal learners (Figure 28). This activity may need to be supplemented with more explanation by the professor to help verbal learners or the overall class may need to be balanced to accommodate both types of learners. Visual learners felt the activity did not increase their interest in mechanics concepts whereas visual learners were indifferent.

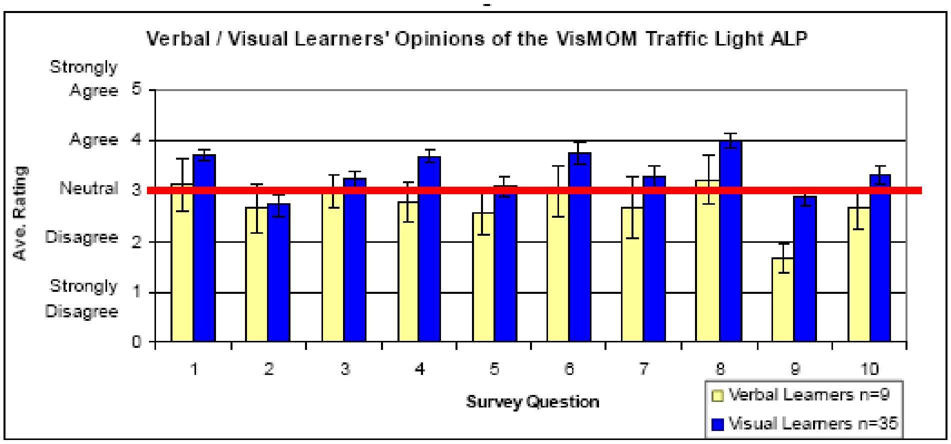


Figure 28: Comparison of verbal and visual learners' opinions of the VisMOM traffic light ALP. (Error bars are 2 standard errors)

4.2.2.3 Student Assessment Results Correlated with Learning MBTI

For most of the survey questions there were no differences based on personality types. However, on a few questions the introverts and extroverts showed interesting differences. Especially for two questions, their opinions were significantly different. Introverts and extroverts' opinions differed on what they had indicated they learned from the ALP (Figure 29). Also, introverts and extroverts had different perceptions on the ALPs ability to help them on the next exam (Figure 29).

4.3. Focus Group Results

To provide additional qualitative information about students' perceptions of the ALPs, an external assessment expert at UT conducted a focus group in Spring 2006. The focus group began with a short survey to get them thinking. It consisted of their perceived effectiveness of the three ALPs used in class and asked them to list of the most difficult topics in mechanics of materials and machine elements. On average students found the activities to be useful or somewhat useful (Figure 30).

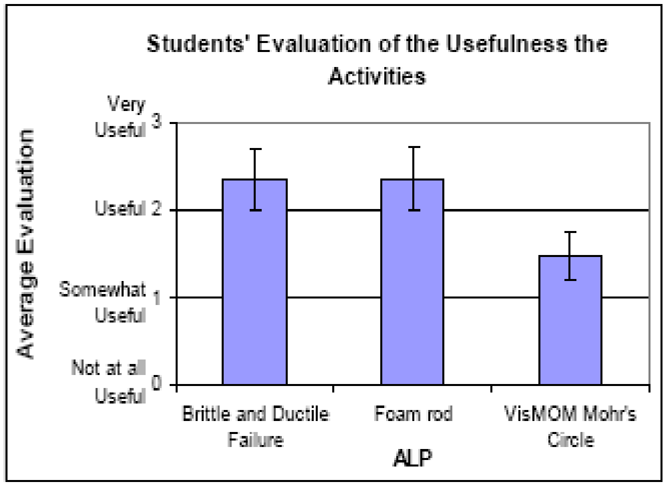


Figure 30: Students' perception of the usefulness of each ALP.

During the focus group the facilitator asked a series of questions to get the students talking. Students made a number of interesting comments that gave guidance on where the activities and their implementation could be improved. Students wanted more ALPs in their class and wished they had been used in previous classes.

Students believed ALPs should be included for every topic. Interestingly, students like the brittle and ductile failure activity but said that activity was not challenging enough for a machine elements class. They felt the activities in generally needed to be challenging. They also believed this set of activities helped improve their conceptual understanding but not their analytical. They also believed activities could be created to assist with both types of understanding.

Students were also insightful about the effects the professor has on a class. One student commented that understanding has more to do with the professors than with the activities. The results would be different with a different professor. This professor gave many examples of where the various equations would be used.

For this particular class, all of the activities had been done individually so the topic of group ALPs was discussed. Surprisingly, students like group work but felt the activities would be less effective in a group. Student comments included, "It's building your intuition, you can't convey that in a group setting." and "[pairs/group work] defeats the purpose of hands-on."

5. Discussion: Addressing the Research Questions

5.1. Question 1: What measures should be used to evaluate ALPs?

As shown by this research, a broad range of measures are required to show the effects of the ALPs on a spectrum of outcomes. These measures include student opinion surveys, focus groups, pre / post quizzes, exam questions and concept inventories. Each of these assessment measures provides different but complementary information about the activities. In many cases for this study, if only one of the measures had been used, the results would have been inconclusive or, possibly, uninformed. Students' opinions give feedback on their evaluation of an activity but do not provide a complete picture. Occasionally, for example in the case of the Foam Beam ALP, it is shown that the ALPs improve student learning, while at the same time students are indifferent to the value of the ALP. Overall, we found that the measures developed for our studies worked very effectively, especially in the context of demographic, personality type, and learning styles insights.

5.2. Question 2: Are ALPs an effective approach for introducing active learning into a mechanics of materials class? Do the ALPs enhance the learning process? What do the students think of the ALPs?

Overall, the effects of the ALPs are very positive. The impact on student learning is quantitatively shown. Students are generally positive about the activities and desired that more be added to their coursework. From the data, it is clear that some of the ALPs can be improved and the results give clear indications where improvements need to occur. The pre and post quizzes and final exam results show students' in lectures using ALPs are learning more from lectures than from the standard lecture.

5.3. Question 3: How are the effects of the ALPs different based on students' learning styles, personalities and demographics? How do the results vary across different institutions, professors and sections of a class?

The ALPs are effective across a range of learning styles and personality types. The ALP evaluations included a number of statistically significant results based on correlations to learning styles, personality types, and students' performance in class. Over all, the activities work well for a diverse set of learning styles, personalities and demographics. Occasionally, these measures when correlated with surveys and quizzes provide insights into the needs of certain student groups. For example, Felder-Soloman's Index of Learning Styles and the MBTI give further insights into possible reasons for the students' opinions of the activity and areas to increase learning across the learning styles and personalities. Recall that, the VisMOM Traffic Light ALP was completed individually rather than being executed as group activity. This implementation could explain why the extroverts felt the activity had helped them less. Personality measure provide a unique method to quantitatively better understand the students and systematically idtentify areas were particular activities can be improved to better meets the needs of certain students.
If the ALPs are expected to be deployed across a broad range of institutions then they must be tested in a number of different situations since results will vary. Variations across institution are observed. Teaching standards and expectations in USAFA's classes are generally very high. USAFA currently uses a variety of active learning approaches and their classes tend to be small. A wide range of learning approaches including active learning are used. This sets the students' expectation for an activity very high which may explain why student opinions tend to be lower than at UT.

6. <u>Conclusion and Future Work</u>

ALPs are an effective way to bring active learning into an engineering class and add another tool to the engineering educator's tool chest. The can be used to seamlessly incorporate active learning into a traditional lecture. As any engineering educator attempts to incorporate new approaches into their classroom, they need to take into account the fact that activities can appear to have a positive or negative impact on learning based on a variety of factors. Educators need to assess their course design with appropriate measures, including student opinions, their observations and quantitative measures of learning such as quizzes and exam question. Educators need to also consider demographic, learning style, personality type, the types of learning environments the students are used to and various other influences when they evaluate the student assessment. Student feedback is dramatically influenced by the learning environments the students are used to. Being able to show that the students learn more even if they do not like the approach because it is not what they are used to is very important.

A total of twenty-eight hands-on activities have been developed. This paper evaluates seven of the twenty-eight using a combination of student opinion surveys, pre/post quizzes, focus groups and a concept inventory. These activities were implemented into restructured lecture classes in three different types of higher learning institutions, a community college, a teaching university and a research university. In general, students were positive about the activities and felt their learning experience was improved. Measurable increases in learning as compared to a standard lecture are observed. Significant variations in results between institutions, professors and sections of a class were observed. Large variations between sections of the same class at the same institution were observed even when both sections were taught by the same professor.

In addition, demographic information, personality and learning styles were also recorded. Most ALPs work well for a variety of personalities and learning styles. Some students' opinions are statistically different based on learning style. Certain activities are embraced and enjoyed more by certain learning styles. In addition it is shown that for some of the activities the students' perceived performance in the class directly correlated with their opinion of the activity. In this case students who were doing poorly in the class felt the ALP increased their conceptual understanding more than students who were doing better in the class. On the same ALP, students who were doing poorly also felt more confused than the students who were doing well.

Our results suggest it is important to take into account a diverse set of measures when evaluating new learning approaches. Future work will include improvements to the existing ALPs, development of additional ALPs and further evaluation.

7. Acknowledgements

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9. <u>Appendix</u>

9.1. Learning Styles & Pedagogical Theory Overview

Educational theory plays a foundational role for the methodology and the development of ALPs. We selected two methods to categorize student’s learning styles: (1) MBTI, (2) VARK, and five models of the learning process: (1) Kolb, (2) Bloom’s taxonomy, (3) Scaffolding, (4) Inductive / Deductive flows, and (5) Learning from Multimedia. Each of these is described briefly below. Although these educational or psychological theories are, of course, not our original work, there are aspects of *the use* of these in our educational innovations that are original. These include 1) the particular mix of two methods to categorize student’s learning styles and four models of the learning process which gives our work a more balanced foundation than may be possible if one bases their approach on one or two theories only, 2) our work showing correlation between MBTI and particular learning propensities is original.

9.1.1. VARK Overview

The present work also builds on student learning preferences as obtained from an instrument called the VARK Catalyst. Rather than being a diagnostic tool for determining a student’s learning preference, the VARK test serves as a catalyst for reflection by the student. The student takes a simple 13-question 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 is Visual (V). This area indicates how much the student prefers to receive information from depictions “of information in charts, graphs, flow charts, and all the symbolic arrows, circles, hierarchies, and other devices that instructors use to represent what could have been presented in words.” The second area is Aural (A). This area indicates the student’s preference for hearing information. The third area is Read/Write (R). This area 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 “perceptual 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.

9.1.2. Kolb Cycle Overview

The Kolb model describes an entire cycle around which a learning experience progresses[i]. 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 [ii,iii]. The cycle is shown in Figure 1.

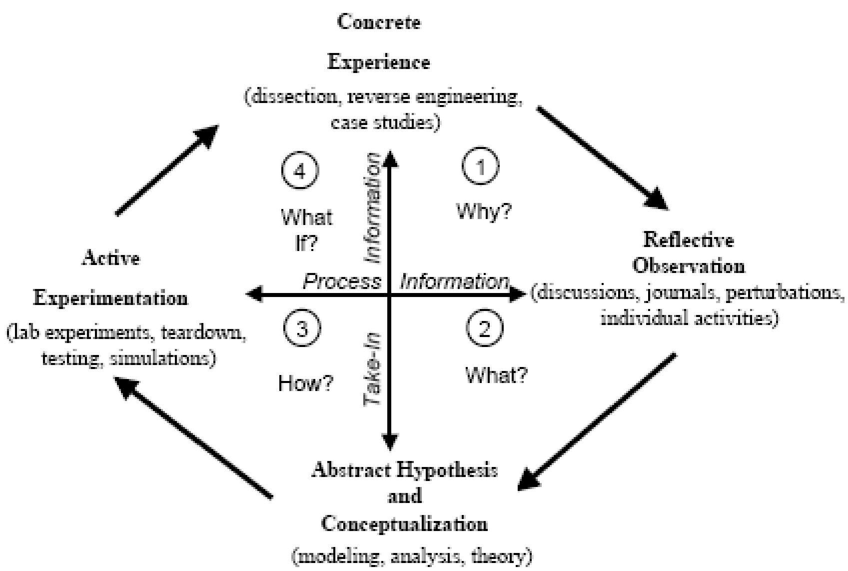

Figure 1: Kolb Cycle

9.1.3. Bloom's Taxonomy Overview

Bloom's taxonomy gives 6 levels at which learning can occuriv (Table 1). In general, a higher level corresponds to a more advanced or mature learning process. Thus, we aspire to focus our instruction in higher education toward the higher levels.

Table 1: Overview of Bloom's Taxonomy

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

9.1.4. Scaffolding and Inductive/Deductive Learning Overview

The term "scaffolding" encompasses the idea that new knowledge is best assimilated when it is linked to previous experiencev,vi. A well-planned flow of material that builds on itself and integrates real-world examples obviously helps provide this "scaffold" for 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 the best learning environment.

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