2006-1332: METHODOLOGY AND TOOLS FOR DEVELOPING HANDS-ON ACTIVE LEARNING ACTIVITIES

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Methodology and Tools for Developing Hands-on Active Learning Activities

Abstract

Active learning hands-on activities improve students' learning. More active learning tools, approaches and activities for the engineering curriculum are critical for the education of the next generation of engineers. A new methodology specifically aimed at the creation of hands-on active learning products (ALPs) has been developed and is described in detail with examples. Methodology provides guidance for a more effective and efficient development process. Educational theory forms a solid basis for this methodology. A set of activities based on the methodology for implementation in a mechanics of materials class is described. Preliminary evaluation results for the ALPs from the US Air Force Academy and Austin Community College show the potential of this approach.

Keywords: Active learning, hands-on activities, methodology, in-lecture activities, mechanics of materials

1. Introduction

Active learning approaches improve students' overall learning[1]. There is considerable literature that addresses the advantages of using hands-on experiences in an engineering curriculum[2,3,4,5,6,7,8,9,10,11,12,13,14,15]. Although the importance of active learning activities is well recognized, little formal guidance in a systematic approach for development exists[16]. This paper presents a methodology for developing active learning products (ALPs) beginning with gathering information from the stakeholders (customers) and ending with final implementation and evaluation in a course. This methodology founds itself on a solid understanding of pedagogical theory much the same way product design theory is tightly tied to an understanding of the physical world. This paper begins with a brief overview of learning styles and pedagogical theory that guide hands-on activity development. Then the method is described in detail with examples. A set of activities based on the methodology for combined loading in mechanics of materials is outlined. The preliminary evaluation results from Austin Community College (ACC) and the US Air Force Academy (USAFA) show students feel these activities are improving what they learn. The future work for this project is then discussed.

2. 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.

2.1 MBTI Overview

The MBTI type indicator includes four categories of preference (Table 1)[17,18,19]. 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 education[8,15,28].

Table 1: 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**	

2.2 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[3]. 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.

2.3 Kolb Cycle Overview

The Kolb model describes an entire cycle around which a learning experience progresses[20]. 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[21,22]. The cycle is shown in Figure 1.

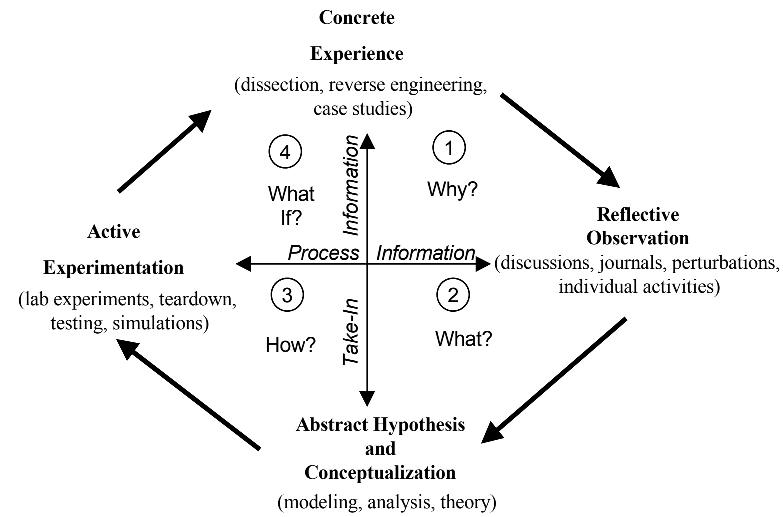


Figure 1: Kolb Cycle

2.4 Bloom's Taxonomy Overview

Bloom's taxonomy gives 6 levels at which learning can occur[23] (Table 2). 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 2: 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

2.5 Scaffolding and Inductive/Deductive Learning Overview

The term "scaffolding" encompasses the idea that new knowledge is best assimilated when it is linked to previous experience[24,25]. 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.

2.6 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.

Guidelines for Multimedia Design (text, diagrams, etc.)[26]

1. Spatial Contiguity Principle: Present corresponding text and illustrations near to each other rather than far apart.
2. Exclude extraneous words and pictures
3. Low-knowledge learners benefit more from well-designed multimedia (illustrations and words) than high-knowledge learners.

Multimodal Design Guidelines (text, diagrams, animations, audio commentary, etc.) based on a Cognitive Model of Multimodal Comprehension[27]

1. 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.
2. Make connections to prior knowledge. Examples include analogies to familiar situations, hyperlinks to definitions or pictures of actual parts.
3. Make connections between elements and their behaviors. In a mechanical domain, this is the physical interaction between components.
4. 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. This can be done by showing snapshots of a system's operation or by asking questions about how the system works.
7. 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. If some users may not understand the basic physical principles governing a given system include links or references to this information.

3. **Methodology for Developing Hands-On Active Learning Activities**

A methodology has been developed to systematically guide the process of developing hands-on active learning activities. It began with a proven product design methodology[28] as a basis, guided with educational theory foundation, and adapted to the hands-on activate learning product (APL) domain. This methodology assists in making the development process more efficient and increases the rate of success. The following sections will described in detail each step of the methodology (Figure 2). Those who are familiar with design methodology for product development will notice similarities. The process begins with defining the stakeholders and collecting their input (gathering customer needs) then defining educational goals and objectives based on this input. The goals and objectives are then prioritized and metrics are defined to measure them. Based on the stakeholder input, and the defined educational goals, a set of topics from a given curriculum are targeted for developing active learning materials. Typically a large set of course topics is defined. Therefore a single topic or a small set of topics is chosen to focus on. The rest of the process from generating ideas, fully developing activities and evaluation is then used recursively until activities have been developed for each sub-set of topics. Finally, a set of activity variants are developed and a single complete set is chosen and evaluated.

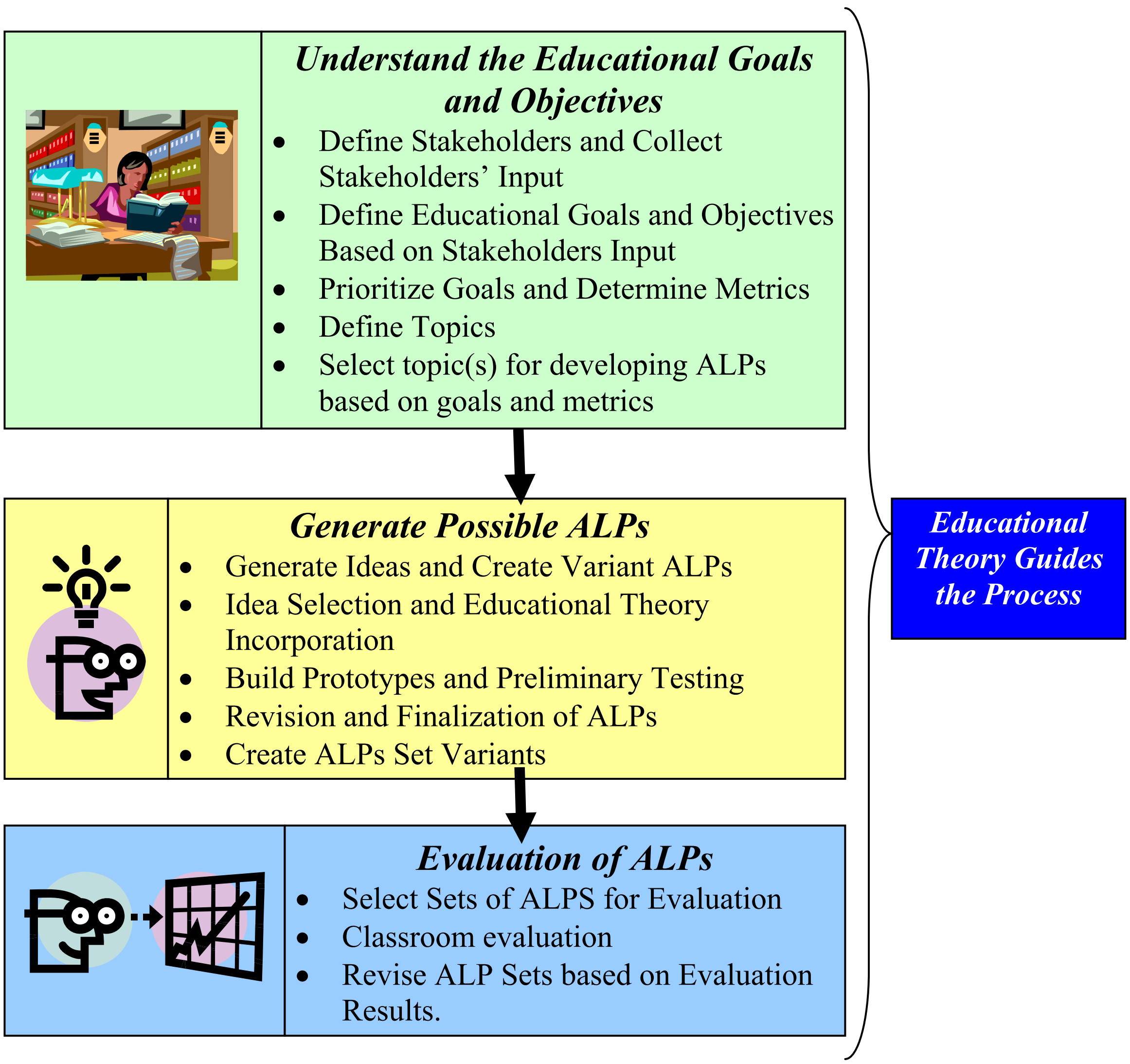


Figure 2: Overview of the Design Methodology for Developing Hands-on Activities

Active learning activities are only one piece of the entire educational curriculum and better serve certain functions within a class than others. Hands-on activities actively engage the student and reinforce difficult concepts. Active learning activities that provide short breaks in lecture maintain student's attention and improve learning. Concentration on a lecture is usually maintained for approximately 15 minutes[29]. By providing short breaks in lecture, learning is increased[30]. These activities are also designed to force the student to provide and test self-explanations of the concepts. Self-explanations also enhance learning[31,32].

Table 3: Functions of ALPs

"Functions" of hands-on active learning activities in the overall curriculum
1. Actively engages the student (increasing motivation and attention)
2. Reinforces and solidifies key and difficult topics
3. Provides a short break in lecture in order to maintain student attention (in-class hands-on activities)
4. Requires the student to provide and test self-explanations
5. Enhances long-term retention of content

3.1 Define Stakeholders and Collect Stakeholders Input

The process begins by identifying the stakeholders or customers for the ALPs. Typically the stakeholders are the students in the class, the professors, the university where the activities are developed, and the community (including industry) that benefits from the students after graduation. The stakeholder inputs can be found using a variety of standardized methods include the like/dislike customer interview method, past experiences, surveys, interviews, and focus groups (see ref. 10 for more details). Relevant literature including common student misconceptions and difficult topics for a given area is another key stakeholder input[33].

Education occurs in a number of different contexts including community colleges, universities, different educational settings such as distance learning and in various cultural settings. Some usage contexts and references to usage factors are described in the educational literature[34,35] (Table 4). Creation of the ALPs should take a variety of contexts into account during development. The usage context for an activity influences the user preferences for a given usage factor (Table 5). The Contextual Needs Assessment Method[36,37] is particularly useful when developing hands-on activities for environments and customers different from what you are familiar with.

3.1.1 Gathering Customer Needs: Contextual Needs Assessment Method

The contextual needs assessment method (adapted and expanded from ref. 36) efficiently guides the designer in defining critical user characteristics that influence product (activity) attributes. *Product usage context* refers to all factors characterizing the application and environment in which a product is used that may significantly impact customer preferences for product attributes. The process begins with brainstorming interview questions and then customizing the context for the given problem. Next the interview processes begins with interviewing prospective customers about what they like or dislike about the current product (a complete class, certain topics within a class, etc.). A few of the contextual factor questions will be answered on this initial interview process. The interview then moves to the more structured contextual factor questions. This process could also be implemented as a survey. From a number of interviews the customer needs list is formed (see refs. 28, 36). Some of the contextual factor questions are best answered through research. If the stakeholders (customers) for some reason are not available for interviews, then researching the contextual factor replaces the interviews.

Table 4: Examples from the Educational Literature of Usage Context and Factors

<table>
<tr><td colspan="2">Example of Educational Usage Factors
(Five factors with primary influence on the teaching-learning exchange)[34]</td></tr>
<tr><td colspan="2">• Teacher</td></tr>
<tr><td colspan="2">• Student</td></tr>
<tr><td colspan="2">• Content</td></tr>
<tr><td colspan="2">• Environment</td></tr>
<tr><td colspan="2">• Learning community</td></tr>
<tr><td colspan="2"></td></tr>
<tr><td colspan="2">Examples of Usage Context</td></tr>
<tr><td>Distance education students
compared to on-campus students[34]</td><td>Finnish students
(Cultural tendencies of Finnish students[35])</td></tr>
<tr><td>• Older non-traditional students</td><td>• Quiet reflection, contemplate ideas individually</td></tr>
<tr><td>• More motivated</td><td>• Shyness in public settings, they do not ask questions in lecture</td></tr>
<tr><td>• More self-disciplined</td><td></td></tr>
<tr><td>• More likely to posses a college degree</td><td></td></tr>
<tr><td>• Higher grade expectations</td><td></td></tr>
<tr><td>• Take more responsibility for their learning</td><td></td></tr>
<tr><td>• Reflect more on course content</td><td></td></tr>
</table>

Table 5: The Influence of Usage Context on Product Attributes

Usage Factor	Usage Context				Product Attribute Preferences Impacted
	Distance Learning	Community College	Teaching College	Research University	
Class Size	~20	10-20	10-20	30-50+	Media, amount of interaction during the activity between the students and the professor
Classroom	Virtual	Small classroom or lab	Small classroom or lab	Large lecture hall	Type of energy available, Media
Type of Students	Non-traditional	Traditional and Non-traditional	Traditional	Traditional	Amount of possible scaffolding from prior life experience

Table 6: Customer Needs Gathering Procedure

Procedure for Understanding Customer Needs & Usage Context
1. Brainstorm interview questions
2. Customize contextual factor template (Table 7)
3. Interview or survey customers
3.1. Interview with the like/dislike method
3.2. Ask any remaining questions in the customized context questions template
4. Form customer needs list

Table 7: Contextual Factor Template (adapted and expanded from 36)

Context Factor	**Question Prompts**
WHERE: Usage Environment	
Classroom characteristics	What technology is available in the room? (e.g. Are the students required to have laptops?) Are power outlets available?
Class size	How many students are in the class?
HOW: Usage Application	
space (when in use)	How much space is available for using product? Are the students at a lab table or a desk?
space (storage)	How much space is available for storing product?
maintenance & parts cost & availability	What is the cost & availability of maintenance & parts?
energy availability & cost	What is the cost & availability of possible energy sources? (e.g. human, battery, gas, electric, biomass)
Who: Customer Characteristics	
user	Who will use the product? (professors, students, universities) Who are the all the customers of this product? (professors, students, universities, industry, community)
education	What is the user's education level? What educational background do they have?
physical ability: strength, control, range-of-motion	Does the user have any physical conditions that need to be considered? What are typical human sensing (e.g. force) and strength capabilities?
relevant cultural background, customs and practices	What types of learning methods have the students been exposed to in the past? Are there any related cultural practices or expectations that need to be considered?

Student background	What is the student's background (previous life experience, interests, pop culture, life experience)? What other commitments do the students have outside the classroom (part time/full-time job, family (single, married, children))?
cost expectations: (purchase)	About how much is the buyer willing to pay to purchase this product?
cost expectations: (operation)	How much is the user willing to pay per use to operate this product? Maintenance cost?
time expectations: professor prep., in-class	About how much time is the professor willing to spend to preparing to use this product? How much time is available for the students to spend using this product?
safety expectations	How safe must the product be?
durability expectations	How long does the user expect product to last?
course purpose, future plans	What are their future plans? (engineer, pilot, graduate school, lawyer, business school, something else, not sure) Is this an elective or required course?
current course and curriculum	How do the activities need to fit into the course curriculum? Should they be in-class, lab, or assigned to be done outside of class?

3.2 Defining the Educational Goals / Objectives based on Stakeholders Input

The next step defines the overall educational goals and objectives based on the stakeholder inputs. The stakeholder may need to improve students' problem solving skills resulting in a educational objective of the students' knowledge being more flexible. Others goals may include low-cost activities with low class preparation time for the professor.

3.3 Prioritize Goals/Objectives and Determine How to Measure

Once the educational goals/objectives are defined, the customer needs are understood, and the "usage context" has been specified these goals/objectives need to be prioritized. These can be prioritized based on the frequency they were mentioned during the interviews combined with the importance that particular item was given by the stakeholder. For less extensive research on these goals/objectives, they may be prioritized based on the experience of the ALPs developer. Another option is to have the customers (students, professors, university, community, etc.) directly rank the priority of each objective during the interview or survey process. An example using this approach for the customer needs is shown in Table 8.

Once the goals/objectives have been prioritized, a set of measurable outcomes or metrics must be defined. For those familiar with design methodology the house of quality is useful tool in the process that implicitly accomplishes the following steps (see ref. 28 for more details). The basic process for developing metrics is the following:

Step 1: Clearly define what is to be measured. This is done when the goals/objectives are set.

Step 2: Choose metrics capable of measuring each goal/objective. In some cases, a given goal/objective may require multiple metrics. However, each goal/objective must have at least one way in which it will be clearly measured. The metrics are the assessment tools by which we will know if the ALPs are effective at accomplishing the goals/objectives set by the stakeholders.

Step 3: Determine the form and/or format for implementing each metric (Table 9). A given metric may be implemented in the format of an in-class quiz, on-line test or even assigned as homework. For other metrics there is a choice to implement them as in-class surveys, interviews or web-surveys. Cost, ease-of-use and the need for controlled conditions guide the choice of the form of the metric and the format of its implementation. In addition, the specific details of the ALP whose effectiveness we are measuring may influence the choice of form and format of the metric. In this way, the process may need to be iterative. A number of websites offer online surveys hosting (for example surveymonkey.com) making this an excellent choice for many metrics.

Table 8: Customer Needs Associated with Hands-On Activity Design[16]

Customer Group	Need	Weight (sum from each group = 1.0)
1- Students	Improve our understanding	0.4
	Improve ability to solve problems	0.3
	Exciting / fun / interesting	0.2
	Real world examples	0.1
2- Professors	Improve students' understanding	0.3
	Low professor preparation time	0.3
	Low class time	0.2
	Improve student motivation	0.1
	Low cost	0.1
3- University	Improve students' learning	0.4
	Enhance university's status	0.4
	Transferable to other classes/profs & univ.	0.1
	Low cost	0.1
4- Community	Improve quality of graduates	0.7
	Enhance universities status	0.3

3.4 Define Topics

The topics that span the course content are identified in this step. This can often be done by simply looking at the course syllabus.

3.5 Select Topic(s) to Develop ALPs based on Goals/Objectives

Once the goals/objectives are prioritized and the metrics to measure them have been developed, a topic or set of topics must be selected to focus on. The topic(s) are chosen based on their perceived ability to positively impact the goals and objectives. Once a topic or small set of related topics is chosen the rest of the process is applied recursively.

Table 9: Example Metrics/ Measures of Effectives

Goal/Objective to be measured	**Tools used in measurement**
Teamwork Skills	Evaluation from teammates
Knowledge Gained	Short answer questions Solve a problem Multiple choice questions Free recall of facts remembered from lecture Exam Grades Homework Grades F. E. Exam
Student Attitudes and Opinions	Surveys: online and paper Focus Groups Interviews
Longer term retention	Final exam questions
Ability to solve real-world or open-ended problems	Score on open-ended project
Solid Conceptual Understanding	Score on conceptually-oriented quiz
Resources required for activity	Time required (in-class & professor preparation)

3.6 Generating Ideas and Create Variant Activities

In this step, specific ideas for ALPs are generated to enhance the topic areas identified above. When generating ideas for ALPs it is helpful to keep in mind that their purpose is to facilitate the positive impact on the goals/objectives previously identified. Idea generation can take many forms from the simple, unstructured listing of ideas by an individual to a formal, highly structured group idea generation technique such as 6-3-5. Numerous formal idea generation techniques exist[38,39,40,41]. The following few basics rules enhance any ideas generation technique.

Basic "Rules" for Idea Generation[42,38,39,40]

- Focus on quantity not quality. Just let the ideas flow.
- Don't judge the ideas during idea generation.
- Wild and crazy ideas are good. They can lead to feasible solutions.
- All people are creative.
- Build from your ideas and other people's ideas.

One example of how the various idea generation methods may be used in combination is shown in Figure 3. Figure 3 simply provides one example of using various idea generation techniques in combination to find a large number of solutions to a problem. The suggested method begins with the preliminary generation of ideas using Mind Maps (Figure 4) and unstructured idea generation. The relevant literature, including other textbooks on closely related topics, is reviewed for ideas and inspiration. Ideas found in the literature are added to the Mind Map including pictures of the various ideas. Throughout the idea generation process, categories, analogies to nature, and analogous products are sought for aid. After reviewing the relevant literature the idea generation process more narrowly focuses on key problems (or topics) being addressed and utilizes a group idea generation technique 6-3-5, check lists and finally organizes the ideas into a comprehensive Mind Map. As a final step, additional information sources such as craft and hardware stores or your personal collection of materials is evaluated for additional ideas.

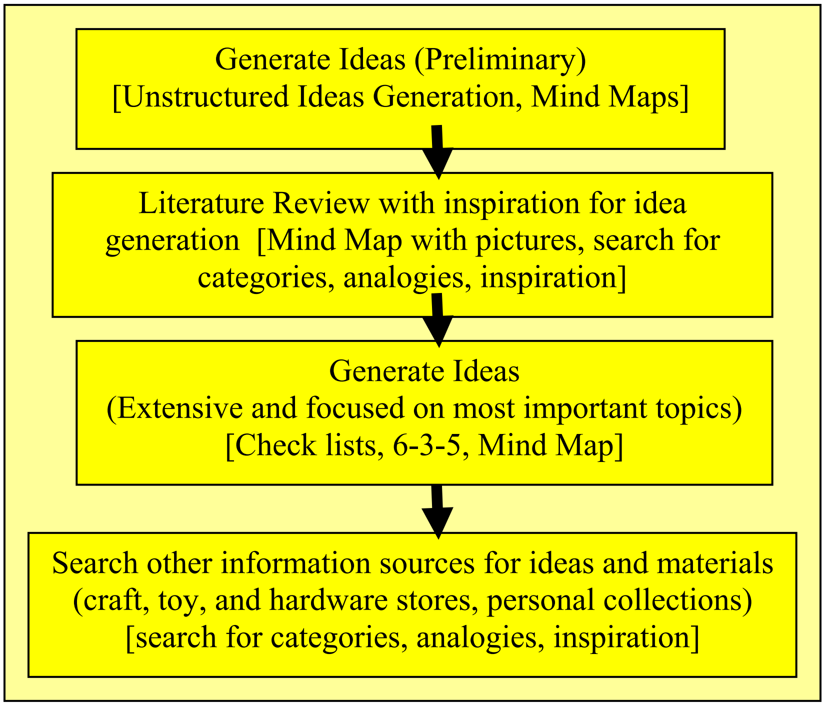


Figure 3: Details of a Suggested Idea Generation Process

3.5.6 Mind Maps

Mind maps begin with the problem statement or a sub-problem written in the middle[28,43] (Figure 4). Ideas are then added branching out from the main topic. Mind maps organize idea generation and facilitate the discovery of categorizes of ideas. As categorizes are observed or come to mind, the category is circle and members of the category radiate out from it.

Categories are the power of mind maps sparking additional ideas that would not have been thought of apart from seeking categories. Mind Maps have been shown to significantly enhance creativity by highlighting relationships between ideas that would not be clearly seen from a more traditional outline organization of the material.

The basic concept of a mind map can be extended to include pictures providing more opportunities (Figure 5). From the mind map with pictures, additional areas to search are discovered visually. Another version of a mind map using sticky-notes is show in Figure 6. Rather than the ideas being connected by lines, each color represents a category. This mind map contains ideas for the Method for Developing Hands-on Activities.

3.6.2 Analogies

Analogies are a well-recognized tool for use in the idea generation process. Analogies can be thought of as products that perform similar, but not identical, functions to the product we are developing. Analogies and examples from nature have been found to be very useful for developing potential concepts in traditional design. We believe they will also prove to be very helpful in developing ideas for ALPs.

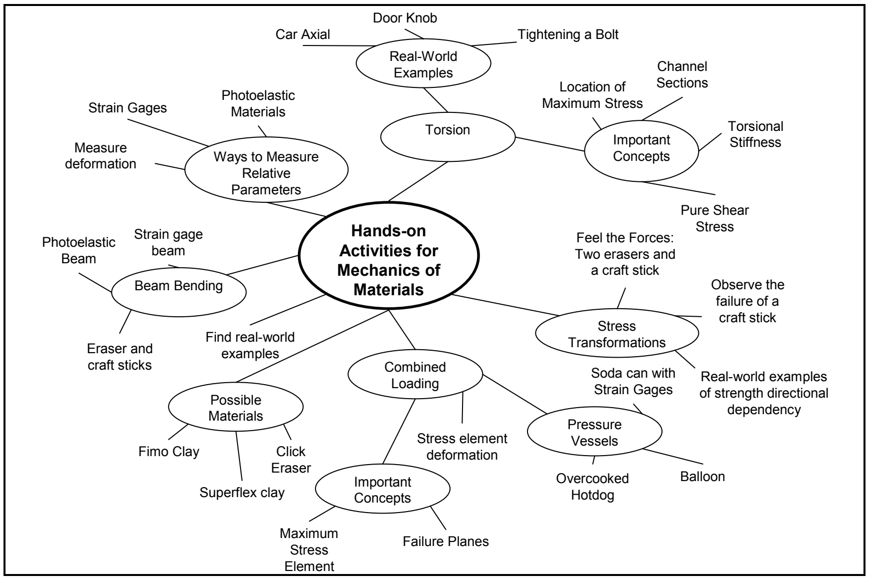


Figure 4: A mind map

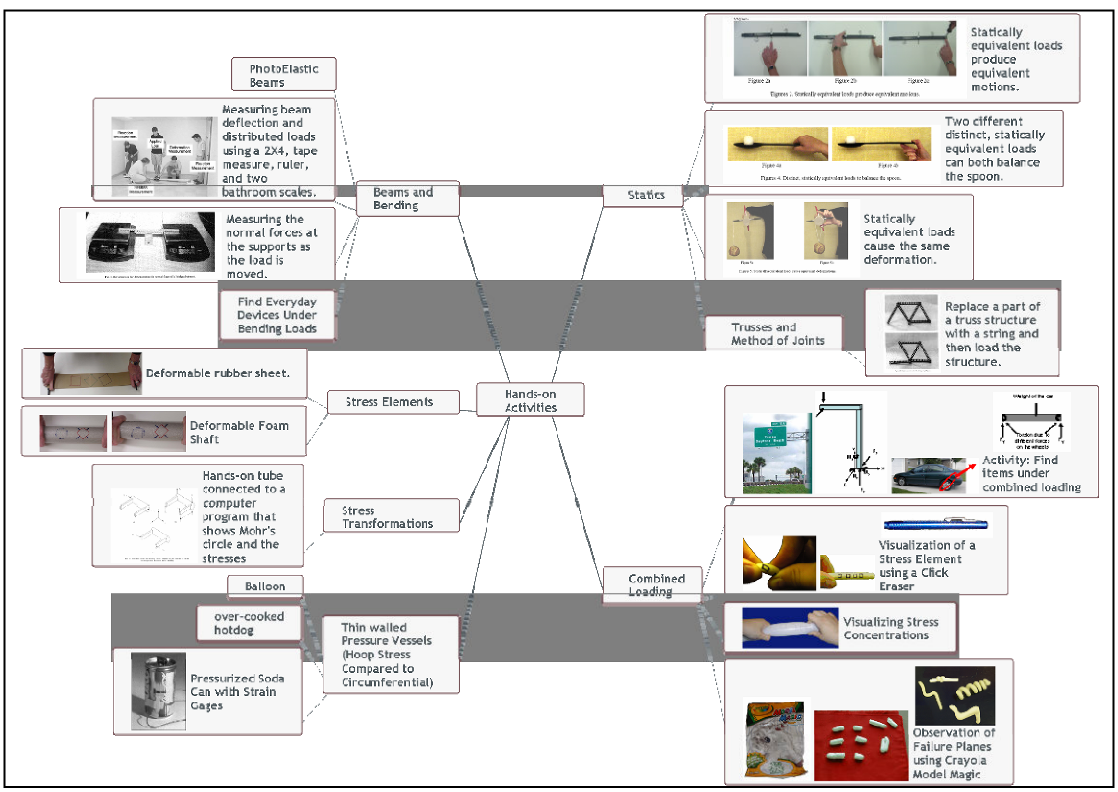


Figure 5: A mind map with pictures of various hands-on activities for mechanical engineering

Figure 6: A sticky-note version of a mind map

3.6.3 Checklists

For product development idea generation, a number of checklists have been developed. These include Eberele's SCAMPER acronym (substitute, combine, adapt, magnify or minify, put to other uses, eliminate or elaborate, and rearrange or reverse), Shore's CREATIVITY acronym (combine, reverse, enlarge, adapt, tinier, instead of, viewpoint change, in other ways, to other uses, yes!) and VanGundy's Product Improvement Checklist[38]. This same approach can be applied in other domains including ALPs development but requires the creation of those lists. In that light, lists analogous to those mentioned above are given in Table 10. Table 11 contains checklists of useful categories for ALPs. When developing a large number of activities, checklists of useful categorizes enhance the process. When idea generation begins to tickle, they provide a tool for restarting the process.

Table 10: Example checklist for finding solutions based on existing activities

	Can the scale of the activity be changed? Can a lab experiment be simplified into a quick in-class experiment?
	What other materials could be used instead of the ones suggested?
	What are the characteristics that make this material useful for illustrative purposes? What other materials can the same characteristics?
	What can be felt? What can be seen? What can be heard?
	What can be easily measured?
	Can it be converted from a group activity to an individual activity or vice versa?
	Should it be an individual or group activity?

Table 11: Checklists of useful categories

Categories of Hands-on Activities	
	Thought Experiments
	Real-world examples
	Find objects
	Objects designed using a given theoretical topic
	Explanation of observed failure
	Simple illustrations using craft store materials
	Concrete, physical experience with the theoretical topic (feel the forces required for static equilibrium, explore the flexure formula by bending a craft stick)
Useful Categories of Real-World Examples	
	Biomedical
	Aerospace
	Vehicles
	Toys
	Kitchen Appliances
	Other Household items (Lawn care, cleaning devices, daily living items)

3.6.4 Group Idea Generation Methods: Brainstorming and 6-3-5

A number of formal group idea generation techniques are available. The term brainstorming is frequently applied to any idea generation technique, even though the name technically was first given to the technique developed and named by Osborn. Osborn's Brainstorming is a familiar group idea generation technique. Osborn's Brainstorming starts with the problem being explained by a facilitator to the group. Then the group verbally exchanges ideas following four basic rules: (1) criticism is not allowed, (2) "wild ideas" are welcomed, (3) build off each others' ideas, and (4) a large quantity of ideas is sought.

Another group idea generation technique particularly useful for engineering design since it includes sketching in the process is 6-3-5. During 6-3-5 six participants are seated around a table, and each silently describes 3 ideas in a fixed amount of time (usually 10-15 minutes) on a large sheet of paper. The ideas can be described using words and, or sketches. The ideas are then passed to another participant. The next participant studies the sheet of ideas and then adds modifications, improvements, combines ideas or inserts new ideas. The "5" in 6-3-5 represents a total of five passes or rounds[40,38,28,41].

3.6.5 Using External Information Sources for Insight
(Searching for Categories, Abstractions and Analogies)

A great number of external information sources exist allowing for a systematic search for ideas. Walking through a hardware, craft or home improvement store gives numerous materials for use in activities. A personal collection of items is another useful tool. High-end specialty gadget stores provide a rich source of innovative technology examples as do numerous technology magazines. The educational literature, text books and example problems provide a rich source to develop new ideas from. As good ALPs are discovered they should be added to a pictorial mind map. External information forms a basis for developing analogies, finding categories of solutions, and developing useful personalized idea generation checklists.

3.6.6 Analogies from information sources: Try mapping aspects the literature examples onto current problem or topics

While searching information sources, look for similarities and abstract principles across multiple examples and then apply these to find more solutions (Figure 7, Figure 8). Try to force-fit aspects of ideas in literature onto your problem. Each activity has numerous characteristics or features available to use in new activities. Usually at least one of the characteristics provides a useful insight and new solution. Seeking analogies and similarities across examples improves the chances an example problem or an abstract principle will be applied in a new situation[44].

For example, one difficult topic for students in mechanics of materials is visualizing the effects of two different loads on a stress element of a three-dimensional object. Two examples showing the visualization of stress elements were found in the literature. The first used a deformable rubber sheet to visual two-dimensional stress elements[45] (Figure 7). The second activity used a foam shaft which was easily deforms torsionally but not axially[46]. Neither activity meet the requirements for visualizing a planar stress element on a three-dimensional object under combined loading, but features from each activity were mapped to a new, analogous solution.

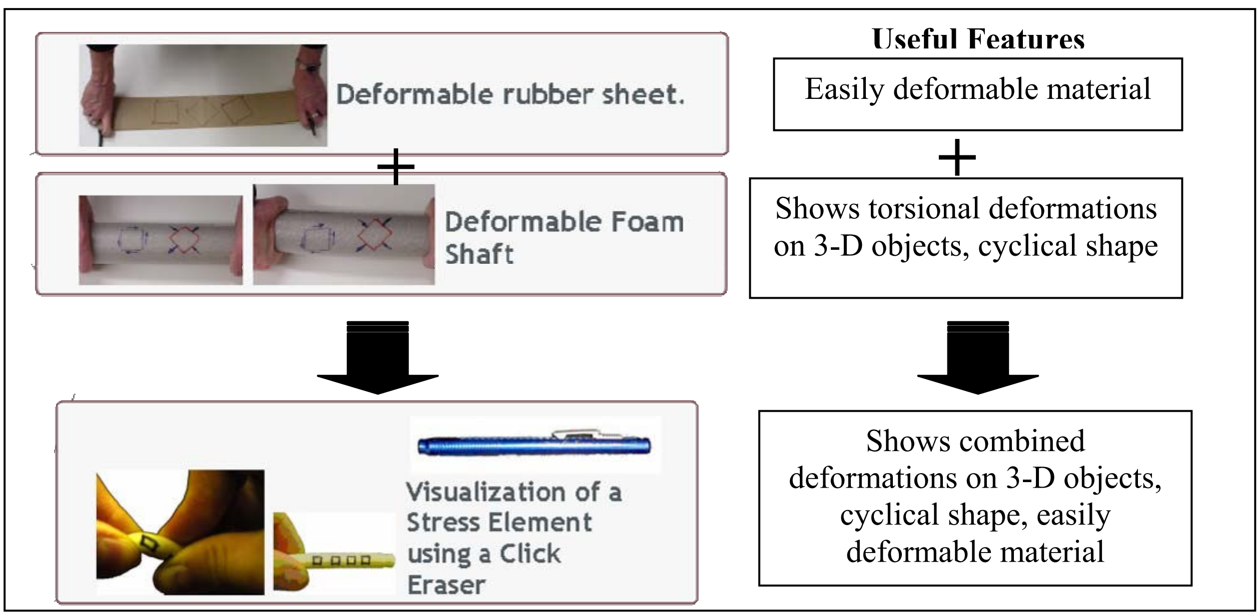
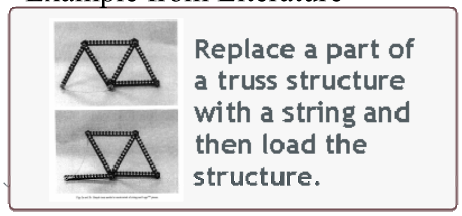


Figure 7: New activity for combined loading based on analogies

Example from Literature



Abstract Principle Derived:

Use a different or less stiff material to highlight the behavior of a component

Figure 8: Example of derived an abstract principle based on an example hands-on activity

3.6.7 Use your students for ideas

Students' ideas provide insight into the type of items that interest them and that they are familiar with. For homework or an in-class brainstorming session students can be asked to find real-world examples when a particular law or principal applies. This activity likely increases motivation and interest in that particular topic.

3.6.8 Create your own checklists for developing new activities

If a number of activities are to be developed, creating a personalized set of checklists aids the process. For example, the hands-on activity Brittle and Ductile Failure (Appendix A) which uses chalk and a tootsie roll leads to the additional category of food items for possible materials. This would lead to the exploration of items like taffies, and hard candies such as jolly ranchers. When new ideas are generated or patterns are observed, these should be added to a comprehensive checklist to be used for future concept generation activities.

3.7 Idea Selection and Educational Theory Incorporation (Embody the Ideas)

3.7.1 Idea Selection using Pugh Charts

After generating a large number of ideas for activities they need to be reduced to a workable number and be embodied into complete activities with worksheet descriptions and questions to answer, see Appendix A and 47 for examples. A tool to aid in the selection process and to further refine ideas is the Pugh chart[48,28] (Table 12). A Pugh chart lists concepts across the top and the criteria for evaluation down the side. The criteria are the goals/objectives defined in earlier steps (this reinserts the stakeholder voice directly into the process) but may be a refined set directly applicable to the particular topic of the activity. Pugh charts use a relative comparison between ideas for selection and also highlight areas where two ideas can be combined to form an improved concept. In Table 12, the Deformable Foam Shaft[45], is chosen as the standard for comparison. The other ideas are then given a "+" if they are better, "-" if worse, and "S" if they are about the same for the given metric. The next step in the Pugh method, "Attack the Negatives" seeks to eliminate the negatives of a given concept by combining, if possible, positives from other concepts. For this example, it leads to trying a different type of foam, such as a foam rod intended for pipe insulation.

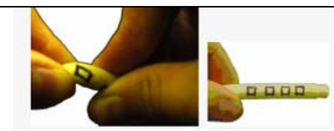
3.7.2 Educational Theory Incorporation

Educational Theory influences the entire development process but plays particular importance as the ideas are embodied and finally developed into complete sets of activities for particular topics or classes. At the single activity level, Kolb's learning cycle, Bloom's Taxonomy, and deductive/inductive learning provide the "laws" for embodying the conceptual activities. Activities should seek the completion of Kolb's learning cycle. The activity may begin with forcing the students to develop a hypothesis and then actively test it. Next they must reflect on their experience. All activities should be designed in such a way they reach for the higher levels of Bloom's taxonomy.

3.8 Build Prototypes, Testing, Classroom Evaluation, Activity Revision and Finalization

After selecting a reasonable number of ALPs for further development, prototypes must be built and a preliminary evaluation done. This initial testing can take the form of simply asking a few students or professors their opinion of the ALPs. Based on this early feedback, the activities are revised. Some ALPs may require numerous iterations before they are deemed worthy for classroom implementation.

Table 12: Example Pugh Section Chart

Concept / Criteria	 Deformable rubber sheet[45] 1	 Deformable foam shaft (pool noodle) [45] 2	 Visualization of a stress element using a eraser 3
Shows stress element on a object well	-	S	S
Shows axial loading well	+	S	+
Shows torsion well	-	S	S
Shows bending well	-	S	S
Low cost	-	S	S
Low prep time	S	S	+
Easily visible stress element	S	S	-
∑+	1	0	2
∑-	4	0	2
∑S	2	0	4

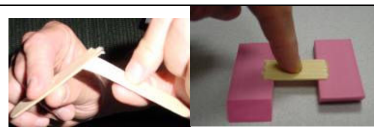
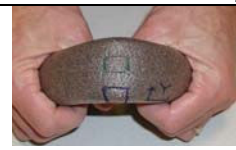
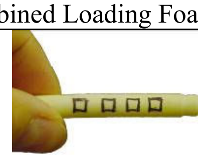
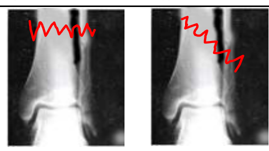
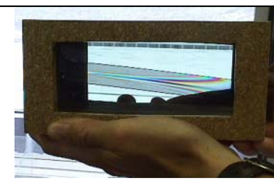
3.9 Create Activity Set Variants and Selection

The completed individual ALPs from the previous steps are then combined into multiple variants or sets of ALPs. One tool for displaying the individual ALPs is a morph matrix[28] (Table 13). From the matrix, multiple sets of ALPs can be selected. Each set variant is then placed in either a Pugh chart or decision matrix[28] for final selection. The bases for the selection criteria at this stage is the metrics and educational theory including learning styles, scaffolding and inductive/deductive learning. Again, this inserts the stakeholders voice into the selection process.

3.10 Complete Set of Activities Evaluation

After selecting one or a few sets of activities, they are incorporated into a class and evaluated as a complete set. Activity evaluation consists of student opinions and objective measures of student knowledge. Student opinions are evaluated through surveys and focus groups. Student knowledge is assessed through short multiple choice quizzes and exam questions. Pre-test and post-test concept inventories, if available, are also used. Further modifications may result as a result of the full assessment process.

Table 13: Example of a Morph Matrix

	Stress Transformation	Combined Loading	Other Topics
1	 Directional Strength Determination	 Combined Loading Foam Rod	 Beams with Strain Gages[49]
2	 Investigation into Directional Orientation in Structures	 Visualization of a Stress Element	 Strain in a Pressure Vessel[50]
3	 Matching Loads and Failure Planes	 Observation of the failure plane using model magic clay	 Hands-On Photoelasticity
4	 Brittle and Ductile Failure	 Visualizing stress concentrations	

4. <u>Activities Developed Based on the Methodology</u>

A series of activities (Figure 9) for combined loading were developed based on an early version of the methodology. The lessons learned were incorporated into the methodology presented in this paper. Four activities have been deemed ready for classroom evaluation, ALPs "Find objects and components under combined loading", "Visualization of stress element under combined loading", "Visualizing stress concentrations" and "Observation of the failure plane for combined loading". These activities show the usefulness of the preceding methodology.

5. <u>Preliminary Results for ALPs</u>

Initial evaluation of the ALPs was carried out at the United States Air Force Academy and Austin Community College. Some details of the assessment are given below. These institutions are two of the higher education contexts we expect the ALPs to be used in. These same ALPs will some be assessed in the context of classes at the University of Texas so that we will have results from a community college, an undergraduate-only military service academy and a top research school. Overall the results are positive, support further ALP development and more in-deep evaluation.

5.1 Results from Austin Community College

Two ALPs “Brittle and Ductile Failure” and “Directional Strength" hands-on ALPs were used at the ACC during the Fall 2005 semester in the mechanics of materials class. A single section of 12 students participated. The topic being covered was stress transformation. The “Brittle and Ductile Failure” ALP focused on deepening students understanding of the differences between materials that fail in a brittle manner compared to a ductile as well as its relationship to maximum normal and shear stresses. The “Directional Strength” ALP aimed for an enhanced understanding of how directional strength affects the failure plane and the role of loading and boundary conditions on failure.

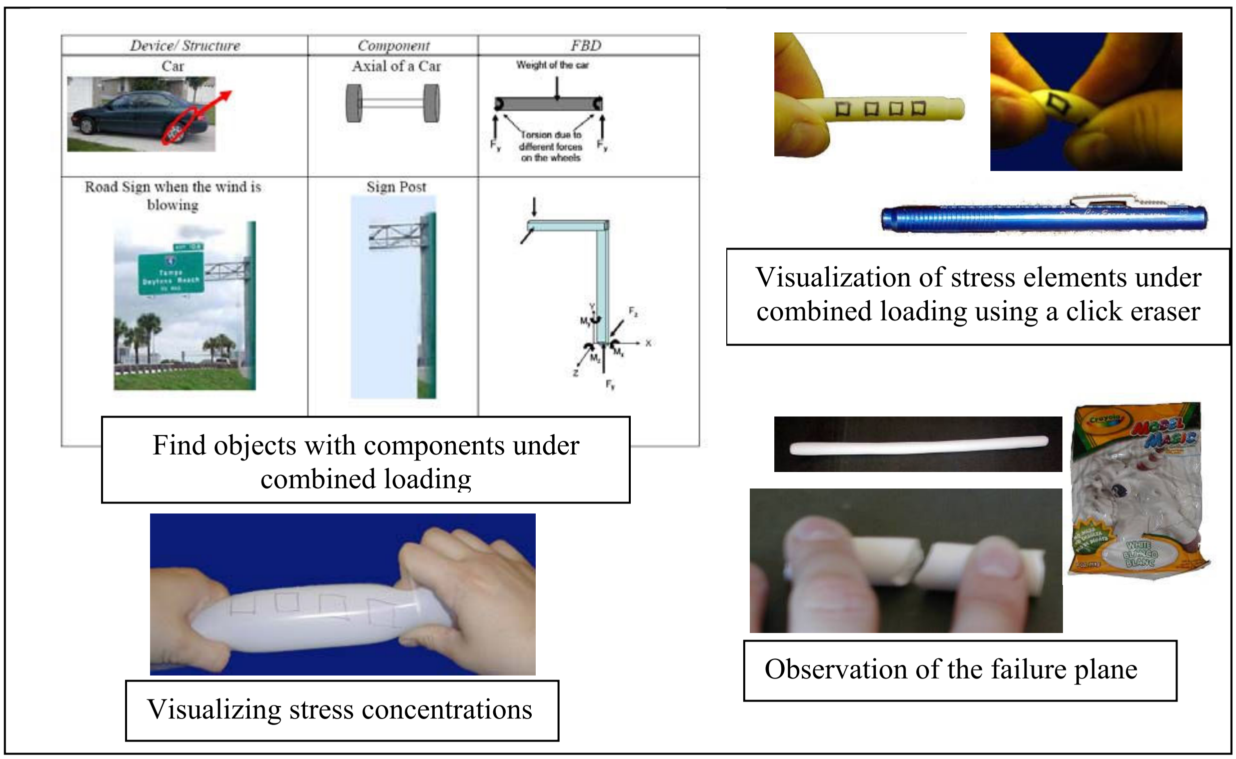


Figure 9: Three activities resulting from the preceding methodology.

5.1.1 Overview of the Brittle and Ductile Failure ALP

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 few pieces of chalk and a couple of Tootsie Rolls. See Appendix A for a complete description of the ALP. Each student twists a piece of chalk and a Tootsie Roll causing torsional failure (Figure 10). 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 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.

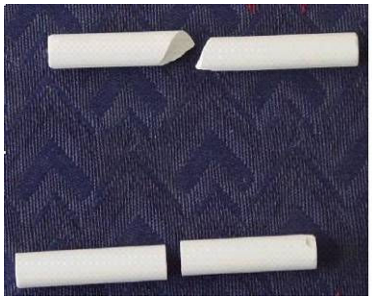
 

Figure 10: Failure modes of chalk in torsion (top) and bending (bottom) and Tootsie Roll in torsion.

5.1.2 Overview of the Directional Strength ALP

The “Directional Strength” ALP guides the students in obtaining concrete experiences in the directional strength nature of wood and its effect on the observed failure plane. Students individually draw a stress element onto two crafts stick and then load them to failure with either a bending load and simply supported end conditions or moments on the ends (Figure 11).

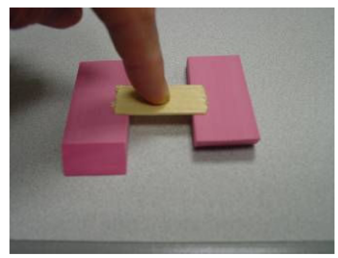
 

Figure 11: Loaded with end moments (left) and simply supported (right)

5.1.3 Initial Assessment at ACC

Students were asked to complete short surveys immediately after the exercises. On the day of the in-class activities, some students were absent and some chose not to take the survey. Most students chose not to answer the demographic questions. Two data points from the “Hands-on Directional Strength Survey” were deemed invalid due to the students clearly not reading the survey. They skipped the top section and then filled in “agree” for all questions. These results are not included. This resulted in a sample size of four and five for the two surveys. Since this was a preliminary assessment, we forced the students to give either a positive or negative assessment rather than including a neutral category.

Overall the surveys show a positive response from the students. The sample size of five is rather small so the results may differ for a larger sample size. Students’ responses are summarized in Tables 15 and 16. For both activities students believe their understanding is improved for key concepts. Interestingly, for both activities, one student felt the activity is a waste of time but almost all the students desire more activities. It appears that one student may desire more hands-on activities in class but did not find these particular activities useful. Students enjoy the brittle and ductile failure ALP more than the directional strength. This may be due to the brittle and ductile failure ALP being the first ALP used during the semester and thus it was more novel and therefore more enjoyable. In general, the students believe the ALP helps them better understand brittle failure but not ductile failure. This shows a possible area for improvement for this activity if the results are replicated with a larger sample size.

Table 14: 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

Table 15: Student Assessment of the Directional Strength ALP

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

5.2 Results from USAFA

5.2.1 Overview of the ALP

The "Combined Loading Foam Rod" hands-on ALP was used at the US Air Force Academy during the Fall 2005 semester in the basic mechanics class. Two sections, each having 18 cadets, participated. The topic being covered was combined loading. 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 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. In this context, the stakeholders (instructors and cadets) both indicated that the ALPs should be developed with the idea of exemplifying the basic conceptual content. This basic conceptual content included understanding the differences between normal and shear stresses, relating the different kinds of stress to different loading scenarios and finally seeing the stress distributions through the cress section of the rod. To help students concretely, visually and tactilely experience these three concepts, the following hands-on ALP was created.

Students were given a section of a foam rod (see Figure 12). In our case this was foam that was intended to be used as insulation for a pipe. A “pool noodle” could also be used for this same purpose. Each rod was approximately 10 inches long and had an OD of 1.5 inches. The material is very flexible. Each rod 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.

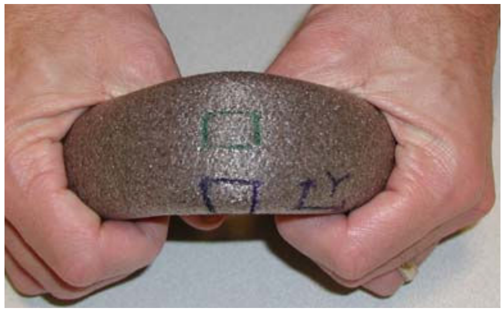


Figure 12: Foam Rod Deformation

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 13 below). Note that the chart that the students received did not have the information in the last 4 columns (Shape, σ_X (y / n), τ_{XY} (y / n) and Comments) filled in. The students were instructed to fill in that data. This takes approximately 20 minutes.

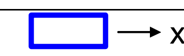
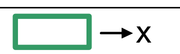
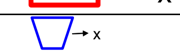
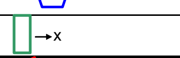
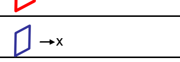
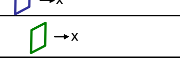
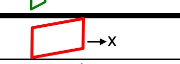
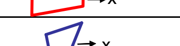
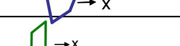
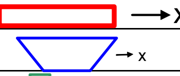
Point	Load Type	Shape	σ_x (y / n)	τ_{xy} (y / n)	Comments
Top (Red)	Axial		yes	no	P / A axial tensile (+) normal stress across entire cross section
Side (Blue)	Axial		yes	no	P / A axial tensile (+) normal stress across entire cross section
Bottom (Green)	Axial		yes	no	P / A axial tensile (+) normal stress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

Figure 13: Completed Chart from the Foam Rod ALP

5.2.2 Initial Assessment

Students were asked to complete a short survey immediately after the exercise. The survey is shown in Figure 14. Thirty eight students took the survey. Results are shown in Table 16 below. Note that all the questions scored above the 2.00 mark except question “d”. Therefore, the general consensus among the students is that the ALP was helpful. However, the students were neutral on the issue of whether the ALP increased their interest in mechanics concepts (question “d”). Recall that most of these students are *not* technical majors. The response with the highest rating (of 3.11) and the lowest standard deviation (of 0.88) was question “b”. The “high and tight” response to this question indicates that the students believed that there was considerable value in them actually manipulating the beam as opposed to having a professor demonstrate the mechanics. This is significant as a demonstration would have taken less time and required less expense in terms of physical hardware. However, it appears that the students believe that the investment (in time and expense) is likely justified. Although this assessment only “scratches the surface” of the issues that we hope to explore in terms of effectiveness of the ALPs, it does indicate that this particular ALP was beneficial to the students.

Feedback on the Hands-on “Foam Beam” Activity

Please circle number that best represents your opinion to the following:

0 = disagree; 1 = partly disagree; 2 = neutral; 3 = partly agree; 4 = agree

a) This activity helped me understand the topic of “Combined Loading” better.

0 1 2 3 4

b) Personally manipulating the foam beam & seeing the results was better than a classroom demonstration (done by the instructor) would have been.

0 1 2 3 4

c) I believe this activity was more effective than using the time for boardwork.

0 1 2 3 4

d) This activity increased my interest in mechanics concepts (like axial, torsion and bending).

0 1 2 3 4

e) I believe this activity helped me prepare for the final exam.

0 1 2 3 4

Figure 14: Survey Used for the Foam Rod ALP

Table 16: Student Assessment of the Foam Rod ALP

	Question “a”	Question “b”	Question “c”	Question “d”	Question “e”
Average	2.76	3.11	2.38	2.00	2.50
Std. Deviation	1.09	0.88	1.07	1.05	0.99

6. Conclusions and Future Work

A methodology for the development of hands-on activities has been developed and is presented. Educational theory provides a theoretical basis that guides the methodology at various stages. Product design methodology acted as an analog for this new method. The method begins with defining the stakeholders and collecting their customer needs. Based on the stakeholder input the educational goals and objectives are outlined. The goals are prioritized and evaluation metrics are defined. The educational goals and the stakeholder input define a set of target topics. A subset of topics is chosen to recursively apply the rest of the methodology. Ideas for activities and variants of the activities are created. Active Learning Products (ALPs) are selected and the educational theory is used in their development. Next, prototypes are built and tested. From the individual ALPs, sets of ALPs are created and selected for incorporation into a class. Finally, a complete set of ALPs is evaluated as part of the curriculum.

After giving the description of the methodology, a set of ALPs based on an early version of the design methodology was presented. The resulting activities support the validity of the method. The results from a preliminary evaluation at ACC and the USAFA show the potential benefits of hands-on activity incorporation. This assessment also adds validity to the evaluation stages of the methodology.

6.1 Future Work

While this paper shows very promising results much further work is planned. Additional ALPs will be developed and through this process validity and refinement will be added to the methodology. A more in-depth evaluation of the methodology will compare and contrast the ALPs developed with the methodology to those developed in a somewhat ad-hoc manner.

Although the initial assessment of the ALPs indicates that students appear to benefit from their use, a more in-depth assessment is required. Further testing will evaluate in detail what the students are learning from the activities, the efficiency of the activities, the activities overall influence on the course, highlight potential areas for improvement and measure how efficient the learning is. Both students' and instructors' feedback will also be used in the evaluation process. Correlations will be sought with students learning styles, as well as other student characteristics (gender, race, type of institution they are attending). An independent evaluator will also assist in the process.

7. Acknowledgments

The work is made possible, by a National Science Foundation grant DUE-0442614, and in part by the University of Texas at Austin College of Engineering, and the Cullen Trust Endowed Professorship in Engineering No. 1. Any opinions, findings, or recommendations are those of the authors and do not necessarily reflect the views of the sponsors. Also, support is acknowledged from the Institute for Information and Technology Applications (IITA) at the USAF 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.

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Appendix A: Example Active Learning Activity

ACTIVE LEARNING: Hands-On Brittle and Ductile Failure

Learning Objectives:

- Tactile and visual feedback on the brittle and ductile failure directions associated with different loading.
- See the principal planes and the affect of the principal stresses
- See that the maximum shear stress can dominate in some loading cases with ductile material

Materials: Chalk and Tootsie Rolls

Figure A1: Fracture surfaces for brittle (chalk) and ductile (Tootsie Roll) materials

Procedure:

1. Note that brittle materials tend to fail due to principal (max normal) stresses (see the CDMoM section on Failure Theories for more details). Ductile materials tend to fail due to maximum shear stress. With this in mind, draw the stress element for two cases: (a) a long cylindrical beam with opposing end moments that cause bending and (b) a long cylindrical beam with end moments that cause torsion.
2. On the two stress elements from step 1, show the planes of principal stress and maximum shear stress.
3. Noting that chalk is a brittle material, predict the failure plane if you load the chalk with end moments that cause *torsion*. On the chalk, draw the failure plane you predict. Apply torsion loads on the chalk until it breaks. Make written notes on the difference between your prediction and the experimental results.
4. Noting that chalk is a brittle material, predict the failure plane if you load the chalk with end moments that cause *bending*. On the chalk, draw the failure plane you predict. Apply bending moments on the chalk until it breaks. Make written notes on the difference between your prediction and the experimental results.
5. Noting that the Tootsie Rolls are a ductile material, predict the failure plane if you load the roll with end moments that cause *torsion*. Take a pen and draw the failure plane you predict. If the Tootsie Roll is hard, you may need to warm it up a bit by rolling it in your hands. Apply torsional loads until it breaks. Make written notes on the difference between your prediction and the experimental results.
6. Can you think of any practical implications of the different failure planes for ductile and brittle materials?

PROFESSOR'S NOTES FOR ACTIVE LEARNING ACTIVITY

Hands-on Brittle and Ductile Failure

Assignment Context: This exercise can be assigned as either homework, as an individual in-class exercise or as a team exercise. If it is assigned as homework, a group revision and turn-in, may carried out during 5 minutes of class time, might create new understanding.

What results do we expect from the students:
1. They need to have stress elements for pure bending and for pure shear for procedure #1.

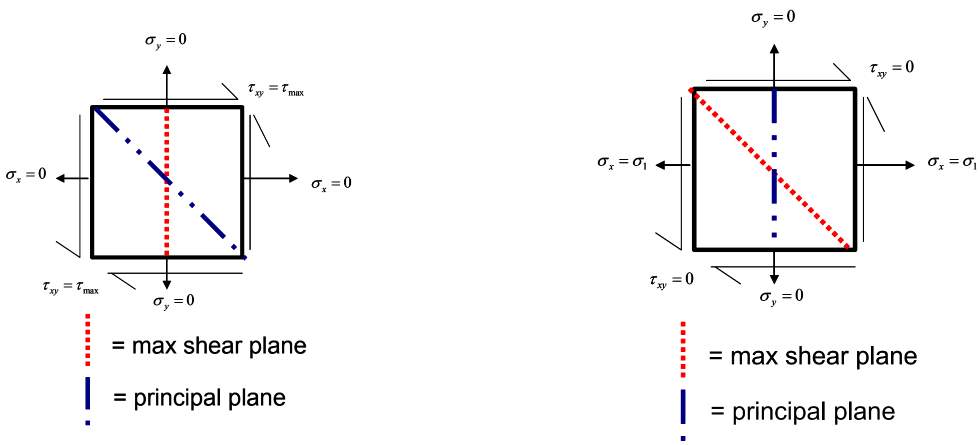

Figure A2: Picture of the stress element for pure bending and pure shear

2. The principal and maximum shear planes should be identified on the stress elements as shown in Figure A2.

3.-5. Predicting the failure planes is based on the type of material (brittle or ductile) and the orientation of the principal planes and maximum shear planes. When the chalk (brittle) is broken with bending loads (which create normal stresses), the stress element looks like the one the right diagram of Figure A2. The failure plane is the vertical plane as this is the principal (maximum normal stress) plane. When the chalk (brittle) is broken due to pure torsional loads (causing pure shear), the principal plane is 45^0 with respect to the vertical. This plane is shown in the left diagram in Figure A2 by the 45^0 line. When the Tootsie Roll (ductile) is loaded in pure torsion, the diagram on the left provides the model. (Note that the surface of the Tootsie Roll will be rough due, in part, to its porous nature. However, the plane of failure is generally vertical. Also note that the students should not pull on the Tootsie Roll – combined loading – during the application of torsion. They should also apply the torsion with their fingers as close together as possible.) For this case the failure plane is the plane of maximum shear stress and is at 90^0 to the long axis.

Some ideas on how to use this result practically, as asked in procedure step 6, might include reinforcing the directions of the failure planes.

Figure A3: Example failure of the chalk (left, torsion on top and bending on bottom) and Tootsie Roll (right).

Some points you might want to stress:
The absence of the case where you break the ductile (Tootsie Roll) material with a bending moment is obvious. The reason that this example is left out is that understanding of the failure plane requires at least cursory knowledge of failure theories. Ductile materials tend to follow the maximum shear stress theory or (normally have even better correlation with) the Von Mises (Distortion Energy) failure theory. These theories predict that the ductile material will fail when the shear stress reaches a value of approximately ½ the yield strength. In the case of the ductile material in bending, the shear stress will be ½ the normal stress. Thus the potential fracture due to normal stress which occurs when the normal stress reaches the yield strength (like a tensile test) occurs at approximately the same load as when the shear stress reaches its critical value of ½ the yield strength. Therefore, it is difficult to determine the failure plane for this special case.