MECHANICAL DISSECTION:
AN EXPERIENCE IN HOW THINGS WORK

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1 INTRODUCTION

I propose that each course offered to undergraduates in a mechanical engineering program should develop their confidence to pose questions, such as:

1. "How did others solve a particular problem?"

2. "How would I (the student) solve a particular problem?"

3. "Why does the solution work?"

4. "What problems am I (the student) interested in solving?"

Furthermore, these courses should be giving students the tools with which to find answers to these questions. This paper discusses the content of and philosophy behind a course that I have developed at Stanford University that addresses of the first of these questions; namely, "How did others solve a particular problem?" The development of this course is being sponsored by the Synthesis Coalition.

The paper begins by enumerating the specific objectives of the course. Then, examples of how the curriculum supports these objectives are given. Finally, the impact that this course may have on courses dealing with the third question of "Why does the solution work?" is outlined in the last section.

2 MECHANICAL DISSECTION: OVERVIEW

A course called "Mechanical Dissection" (ME99) being developed at Stanford is an attempt to get students to ask (and learn to answer) the question of “How did others solve a particular problem?”. It is based on the hypothesis that current design and mechanics courses can be made more meaningful to students if preceded by a lab-based course aimed at exposing students to technology that surrounds them. This is especially true for students who have had limited “hands-on” experience in their lives. I believe that students should and can improve their ability to reason about function and form in mechanical designs. The course is designed to be positioned as a foundation experience, prior to mechanics courses. It is targeted at freshman- or sophomore-level engineering students and assumes exposure to basic physics but *no* prior exposure to the vocabulary of engineering, statics, strength of materials, or sketching.

Specifically, the objectives of the course are:

1. to give mechanical engineering students an <u>understanding of mechanical artifacts</u> through hands-on dissection experiences and exposure to the vocabulary of mechanical systems,
2. to develop an <u>awareness of Design Process</u> through hands-on design exercises/ assignments that highlight the importance of functional specifications in design and how they map into specific functions, and the non-unique mapping between functional specifications and the final design solution (*i.e.*, multiple solutions),
3. to make students aware of the <u>power of clear, concise communications</u> (oral, written and graphical) by having them present descriptions of mechanical artifacts and critique each others work,
4. to develop <u>resourcefulness and problem solving skills</u> through labs that require students to reason about function of three-dimensional objects.

In some ways this course can be thought of as a case studies course, where the case is the hardware itself. One of my colleagues [1] recently likened the objectives of ME99 to learning language; we start exposing our children at a very young age to stories and literature by reading to them, and then at a slightly older age we teach them the rules of language and encourage them to read as well as create their own stories. ME99 is a course about exposure; exposure to the language of the mechanical things that surround us. It is an exposure that may be missing for many of our students in current programs. Furthermore, I believe that such early exposure has the potential to impact subsequent courses.

The next sections discuss how the specific threads (i.e., Labs, Lectures, Class Activities, Student Presentations) in the course support the objectives enumerated above.

2.1 Understanding of Mechanical Artifacts

Hands-on experiences

There is no substitute for rolling up your sleeves and digging in. I believe that we "see" with our hands as well as with our eyes. There are a number of exercises in ME99 that have students work with their hands to study the artifacts (which are really solutions) created by others. They include:

• Labs

The students in ME99 participated in four actual “dissections”, consisting of the disassembly and reassembly of an artifact. Each dissection was preceded by a discussion or activity that related to the external functioning of the artifact. The artifacts considered this year in their order of presentation were:

1. an HP printer (dissected during the second class period in teams of three, with a coach actually doing the disassembly and guiding the group through the printer)

2. a fishing reel (preceded by a fishing trip so that all students would have an appreciation and awareness of fishing; dissection done in teams of two with explicit instructions)

3. a ten-speed bicycle (done in teams of two with some guidelines)

4. an artifact of each student’s own choosing (an individual project which was self-guided with staff support).

Students were required to answer a series of questions related to the fishing reel and ten-speed bike. The products of the individually selected artifact (4.) were a term paper and participation in a poster session. These two assignments will be addressed later.

• Individual Artifact Presentations

Throughout the course students were assigned artifacts about which they were to give ten-minute class presentations. These artifacts ranged from toasters and locks to washing machines and faucets. In preparation for their presentation, most students found (on their own) an example of the artifact to take apart in order that they might really understand its function.

Other benefits of this hands-on approach are that students develop improved awareness of the things around them, they get experience in the use of a variety of tools (from wrenches to catalogues), and they gain confidence in their ability to take things apart.

Learning the vocabulary of mechanical systems

Part of feeling comfortable about the mechanical artifacts around us is knowing the vocabulary associated with them. The students in ME99 have learned this vocabulary in a number of ways. One way is by completing the Labs, and associated readings and questions (as discussed above). Another is through formal "reductionist" lectures. These lectures have included such topics as gears, fasteners, bearings and other mechanisms. All of these lectures featured working models so that students could really see and feel the relationships between mechanical components. It is important to note that these lectures were coordinated with the Labs and Class Activities.

For example, after the students had completed rebuilding the brake system on the ten-speed bikes, a lecture was given on the loads in this particular subsystem. A free-body diagram of the system was constructed as part of the lecture. Then the issue of material selection for the calipers was addressed. This provided a nice introduction for a field trip to a mechanical test lab, where a series of material tests were run. Upon returning to the classroom the data from tests were considered, and the idea of normalizing load and deflection into stress and strain, respectively, was introduced. Other material characterizations such as yield strength were discussed. Using a simple beam analysis of the brake caliper, stresses in the caliper were then compared with material stress-strain curves for final material selection.

2.2 Awareness of Design Process

As students' understanding of the mechanical operation of the artifacts around them grows it is important that they realize that these artifacts are in fact the result of much thought, iteration, and analysis; *i.e.*, the design process. These products do not just “happen”. This realization should include the ideas that all designs represent trade-offs, and that there are likely to be numerous solutions to a single design problem (*e.g.*, side pull and center pull brakes on a bicycle). It is also important to understand that the process typically starts with a perceived need and then becomes a set of functional specifications. These ideas have been developed in the class through:

- Individual Artifact Presentations
  As was mentioned above, throughout the course students were assigned artifacts about which they gave ten-minute class presentations. It was required that the first portion of these presentations be devoted to a discussion on what the student thought the designer's functional specifications were. The last portion of each presentation was devoted to comparing the particular example of the artifact that the student had investigated with the initial functional specification list (e.g., which specifications were ignored, which were realized).

- Class Activities
  One of the class activities had students design, prototype, manufacture, and operate "Bodiometers". These devices, made out of Legos™, were used to take measurements on a human body. In this exercise students were able to experience the full range of the design process, including both the joy of seeing your design actually work, and the frustration of handing off your work to someone else to manufacture. This exercise provided an excellent foundation for two subsequent case study-based lectures on the design and development of real artifacts (given by two guest lecturers who are design engineers).

2.3 The Power of Clear, Concise Communication

Developing effective communication skills is an important part of this course. It is not enough to see how something works inside your own head; you must be able to create an image of its operation in the minds of others. In fact, the very process of explaining things to others may improve your own understanding. The Individual Artifact Presentations discussed above are one attempt at giving students experience in making technical presentations. Students were encouraged to use models, overheads, videos, and the white board as presentation aids. Furthermore, each student filled out evaluations on each presentation, which were then returned to the speaker.

In the final Lab assignment, each student chose an artifact that he or she wanted to spend approximately three weeks researching. Items selected included a two-stroke engine, stereo speakers, and a sewing machine. The students were required to find an example of the artifact (from, for example, a junk yard) to dissect; contact people involved with manufacturing, designing, using and maintaining the artifact; and research some aspect of its history. The products of this endeavor were a formal report and participation in a poster session. Attendees at this poster session were freshman interested in engineering, and local area eighth graders. Each of the ME99 students gave a five-minute presentation to accompany their poster.

2.4 Development of Resourcefulness and Problem Solving Skills

Good mechanical engineers and designers need to be resourceful. This means realizing that all answers are not in textbooks, professors do not know everything, and that there is a world out there with a lot of information. A number of the assignments have required a certain level of resourcefulness; *e.g.*, the Individual Artifact Presentations required that the students find an example of the artifact.

The course has also attempted to develop problem solving skills, including using one's intuition. Examples of this are having students

- come up with the functional specifications for an existing artifact (asking, “what problem(s) was the designer trying to solve?” In some ways this is reverse engineering.)

- figure out how to take something apart (spatial reasoning problem solving skills).

3 HOW WELL DID IT WORK?

Ten students took ME99 during its first offering in the Fall of 1991. In general these students did *not* fit the profile of the “targeted” student in terms of contemplating engineering as a major. They all did, however, exhibit a keen sense of curiosity about things around them. They represented various levels of technical experiences. The majors represented by the ten were Computer Science, International Relations, Mechanical Engineering, Product Design, Neurosciences, Mathematics, and Stanford's Independently Designed Major. Most of the ten students felt that ME99 was “a wonderful course.” Perhaps the deck was stacked in this direction to begin with when one is offering a new elective class where all of the individuals taking it are there by choice.

Lest one think that the course went perfectly, there are areas that need revision. Some of these are organizational in nature, others are exercises that just did not work (or worked but took too much class time). Periodic discussions with the students allowed us to get feedback on how the course was going in real time (which allowed for "mid-course" correction). Two examples of areas that were identified for further work are:

- *Level of lectures*
  Because of the diverse group taking the course, some found the material covered in the lectures was too difficult, some found it too easy. This should be less of a problem in the future if the background of the students taking the course is more “homogeneous”. This is still a very important issue to consider. It does invite one to think about a “hypercard” lecture in which students could begin at a level on a particular topic that matches their experience base. Some work on this topic has been started at MIT [2]. Any such developments should also include boxes of physical models to accompany the software presentation.

- *Grading*
  A number of students felt that because this is an “experiential” course, and not a science-based course, it might be good to offer it on a pass-fail basis. I think that is a good idea, IF the pass status included mandatory class participation.

4 POTENTIAL IMPLICATIONS OF THIS COURSE

The ideas presented in ME99 should naturally lead us into courses that address the question of “Why does the solution work?” (question 3. in the list presented in the Introduction). Courses developing the tool set to answer this question might be labelled as analysis (or mechanics- or science-based) courses; as opposed to design courses. Examples are statics, strength of materials, and dynamics.

To be honest, I do not think that our current analysis courses are, in general, framed in the context of this “Why?” question. Most are framed in terms of “How do you do statics, or dynamics, or strength of materials?” That is not to say that there have been attempts to make change. For example, Prof. Laura Demsic's work in Open-Ended Problems in Statics at Univ. of California-Berkeley [3], and Prof. Carl Peterson's work at MIT [4] in introducing a design flavor to strength of materials, are certainly attempts to change the sort of questions that we are asking in mechanics courses. I see Prof. Demsic's work as introducing the question of “Why does the solution (of others) work?” and Prof. Peterson's as introducing both the questions of “How would I solve a particular problem?” and “Why does (my) solution work?”. It is interesting to note that Prof. Peterson describes his work as a mixed success.

The ground work laid in a course like ME99 creates the possibility of introducing more "Why does the solution (of others) work?" questions into mechanics courses. The basis for these questions would be the hardware/ experience that students have had in ME99 (as discussed above). In many of the problems, the students would be expected to go out and find hardware and make measurements of it before attempting to answer the question. Examples might include:

Statics:

Free Body Diagram (FBD) of the gear train in the HP desk-jet printer.

FBD of side-pull bike brake system including frictional considerations. The problem could be extended to calculate stopping times using dynamics that students have already had in physics.

Identification of the types of internal and external loads (*e.g.*, compression, tension, bending) in mechanisms such as four-bar linkages.

Identification of load paths.

Bike equilibrium problems, including weight distribution (actually have them make measurements).

Dynamics:

deceleration of a bike
banked bike problems

Strength of materials:

loads on the front fork of a bike, resulting stresses, plus comparison to material strength.

loads of a fishing pole, resulting stresses, plus comparison to material strength.

loads on various bike frame members, and resulting stresses, plus comparison to material strength. Have students design a downtube with double or triple butted tubing.

Students would be mapping the tools of these mechanics courses onto physical examples that they already understand in terms of mechanical function. It seems to me that this would very likely mean that the "stuff" of mechanics would "stick" better, and that the education process would more closely mirror actual practice (where design is most often done prior to analysis, and those doing the analysis understand the function of the artifact).

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6 REFERENCES

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