DESIGNING A FIRST YEAR ENGINEERING COURSE

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Abstract

How to Model It: Building Models to Solve Engineering Problems is a first-quarter first year course that focuses on problem formulation, design and construction of models, and drawing conclusions from modeling results. Students work in small teams on several problems selected from various engineering contexts. They learn how to use computer-based modeling tools, including spreadsheets and equation solvers. The entire course is problem-based, that is, the emphasis is on formulating and solving problems.

The bases for the design of **How to Model It**--engineering, engineering design, modeling, cooperative learning, teamwork, etc.--are described and related to the operation of the course. Examples of the slightly open-ended problems that are used to engage the students are described. Concepts and heuristics that students learn are discussed. Finally, the active learning approach to getting students to create, to design, and to think is described.

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Introduction

Following a recent teaching assistant training session, one of the graduate students who had taken my course **How to Model It: Building Models to Solve Engineering Problems** came up and told me how much he enjoyed the course. He said my course was the only one in which he had gotten open-ended problems to formulate and solve in a cooperative group. Then he said "In your course was the only time a professor asked me 'What do you think?'" I was simultaneously gratified and horrified. This graduate student had just spent four years successfully completing an undergraduate engineering degree, and only in his first quarter did he get open-ended problems that he had to formulate and solve with a group of his peers. On exploring, I found that this is not an unusual situation. Eleanor Duckworth, Professor at Harvard's School of Education and science educator, wrote in a recent article in the *Harvard Educational Review*[1]:

> In my entire life as a student, I remember only twice being given the opportunity to come up with my own ideas, a fact I consider typical and horrible. I would like to start this paper by telling how I came to realize that schooling could be different from what I had experienced.

This paper describes a very different approach to the design and teaching of a first year engineering course.

Background

The design of the **How to Model It** course is based on changes that have occurred and are occurring in the way engineering design is done, in what we know about how engineering design is learned (and taught), and changes in the way engineers work in the world. The paper builds on ideas presented in previous papers, including "Educational engineering,[2]" "The nature of engineering expertise[3]," "To engineer is to model[4]," "Building engineering models[5]," and "Prediction and elimination of hot tearing in the casting process by using a 'hybrid modeling' approach[6]".

A lot has been written about engineering and engineering design. The latest wave of books is no exception[7] [8] [9]. My colleagues (Vaughan Voller and Randal Barnes) and I have taken a modeling approach to helping students learn about the engineering method and how to do engineering design. Recent books are emphasizing this connection between modeling and design and extending it substantially[10] [11].

Modeling in its broadest sense is the cost-effective use of something in place of something else for some cognitive purpose (Rothenberg[12]). A model represents reality for the given purpose; the model is an abstraction of reality in the sense that it cannot represent all aspects of reality. Any model is characterized by three essential attributes: (1) *Reference*: It is *of* something (its "*referent*"); (2) *Purpose*: It has an intended cognitive *purpose* with respect to its referent; (3) *Cost-effectiveness:* It is more *cost-effective* to use the model for this purpose than to use the referent itself.

An essential aspect of modeling is the use of heuristics[13]. Although difficult to define, heuristics are relatively easy to identify using the characteristics listed by Koen[14]: (1) Heuristics do not guarantee a solution; (2) Two heuristics may contradict or give different answers to the same question and still be useful; (3) Heuristics permit the solving of unsolvable problems or reduce the search time to a satisfactory solution; (4) The heuristic depends on the immediate context instead of absolute truth as a standard of validity. A heuristic is anything that provides a plausible aid or direction in the solution of a problem but is in the final analysis unjustified, incapable of justification, and fallible. It is used to guide, to discover, and to reveal. Heuristics are also a key part of the Koen's definition of the engineering method: *The engineering method is the use of heuristics to cause the best change in a poorly understood situation within the available resources* (p. 70). Typical engineering heuristics include: (1) Rules of thumb and orders of magnitude; (2) Factors of safety; (3) Heuristics that determine the engineer's attitude toward his or her work; (4) Heuristics that engineers use to keep risk within acceptable bounds; and (5) Rules of thumb that are important in resource allocation.

Recent work on engineering design indicates that design is a more social process than we once thought. Larry Leifer (Stanford Center for Design Research) claims that engineering design is "a social process that identifies a need, defines a problem, and specifies a plan that enables others to manufacture the solutions." Two of Leifer's recent Ph.D. graduates--Scott Minneman (The social construction of a technical reality: Empirical studies of group engineering design practice) and John Tang (Listing, drawing, and gesturing in design: A study of the use of shared workspaces by design teams)--argue that design is fundamentally a social activity. They describe practices such as "negotiating understanding," "conserving ambiguity," "tailoring engineering communications for recipients," and " manipulating mundane representations." Using predominantly ethnographic procedures they conduct research using what they describe as a "rigorously subjective methodology." Some of the cutting edge of design research (being conducted at Stanford and Xerox Palo Alto Research Lab) is now confirming what Billy Koen described 10 years ago--there is no simple or guaranteed approach to engineering design (no algorithms, in other words). There are, however, many very good heuristics--apply science where appropriate, use an engineering morphology, use feedback to stabilize design, make small changes in the state-of-the-art.

Changes occurring in how engineers work in business and industry, summarized in the following table, have serious implications for how we prepare engineering graduates for working in the 21st century.

A Paradigm Shift: Manufacturing 2002[15]

Old Paradigm	New Paradigm
Inspectors responsible for quality	Worker responsible for quality
One worker at a machine	Self-directed work teams at machines
Static job assignments	Worker empowerment
"Management thinks, you do"	"Management and worker think and do"
Quantity over quality	Quality over quantity
Price and supply	Quality and customer service
Competition	Collaboration
Collusion/antitrust	Manufacturer networks
Individual incentives	Group incentives
"Let the buyer beware"	External and internal customers
Local orientation	Global orientation
Single-job skills	Job clusters/skill families
Muscle power	Smart machinery
Individual efforts	Partnerships
Sporadic training	Constant training
"Degree" education	Lifelong or competency-based learning

Similar changes are outlined in numerous references. Byrne[16] and Weisbord[17] are two of my favorites. Many of these changes have direct implications for engineering education. The changes that are occurring in business and industry suggest that we should consider changes in engineering education to prepare our graduates to function effectively in the "new paradigm" companies. The "Made in America" study[18] recommended the following changes for MIT:

1. Broaden its educational approach in the sciences, in technology, and in the humanities and should educate students to be more sensitive to productivity, to practical problems, to teamwork, and to the cultures, institutions, and business practices of other countries.

2. Create a new cadre of students and faculty characterized by (1) interest in, and knowledge of, real problems and their societal, economic, and political context; (2) an ability to function effectively as members of a team creating new products, processes, and systems; (3) an ability to operate effectively beyond the confines of a single discipline; and (4) an integration of a deep understanding of science and technology with practical knowledge, a hands-on orientation, and experimental skills and insight.

3. Revise subjects to include team projects, practical problems, and exposure to international cultures. Encourage student teaching to instill a stronger appreciation of lifelong learning and the teaching of others. Reinstitute a foreign-language requirement in the undergraduate admissions process.

4. Offer as an alternative path to the existing four-year curriculum a broader undergraduate program of instruction, followed by a professional degree program.

5. Establish a major interdepartmental research center on industrial productivity, possibly to include existing efforts, with a broad research program spanning from office productivity to factory-floor productivity.

6. Increase the community's awareness of the critical problems surrounding national productivity and university education.

Course Goals

The goals for **How to model it**, as listed on the syllabus, are:

1. Learn about formulating, modeling, and analyzing engineering problems
    Master the concepts, principles, and heuristics
    Develop skills for formulating and solving problems
2. Improve skills for using tools (computers) for modeling and problem solving
3. Improve writing and speaking skills
4. Improve skills for working effectively with others

These goals are consistent with current thinking about the purpose of engineering schools. Deming associate and engineering educator, Myron Tribus summarized the purpose of engineering schools as follows[19]:

> The purpose of a School of Engineering is to teach students to create value through the design of high quality products and systems of production, and services, and to organize and lead people in the continuous improvement of these designs.

Notice that in Tribus' statement, management is considered a part of, not apart from, engineering. He also elaborates on the importance of group work for learning to engineer:

> The main tool for teaching wisdom and character is the group project. Experiences with group activities, in which the members of the groups are required to exhibit honesty, integrity, perseverance, creativity and cooperation, provide the basis for critical review by both students and teachers. Teachers will need to learn to function more as coaches and resources and less as givers of knowledge.

The importance of teamwork in business and industry is embedded in the concepts of concurrent (or simultaneous) engineering and total quality management. Two recent citations elaborate on this point:

> In concurrent engineering (CE), the key ingredient is teamwork. People from many departments collaborate over the life of a product--from idea to obsolescence--to ensure that it reflects customers' needs and desires. . .Since the very start of CE, product development must involve all parts of an organization, effective teamwork depends upon sharing ideas and goals beyond immediate assignments and departmental loyalties. Such behavior is not typically taught in the engineering schools of U.S. colleges and universities. For CE to succeed, teamwork and sharing must be valued just as highly as the traditional attributes of technical competence and creativity, and they must be rewarded by making them an integral part of the engineer's performance evaluation[20].

> Team development must precede all other kinds of improvement initiatives and teams, more than executive leadership, cultural change, TQM training, or any other strategy, account for most major improvements in organizations. Team development must be strategically placed at the very center of TQM and must form the hub around which all other elements of TQM (customer satisfaction, supplier performance, measurement and assessment, and so on) must revolve... Teams are the primary units of performance in organizations. They are, inevitably, the most direct sources of continuous improvement[21].

Course Topics

Problems such as the 10 problems in our book How to Model It (ping-pong, purging a gas storage tank, the student's dilemma, tennis, etc.) are given to introduce and help students learn engineering and modeling concepts, including

identification of variables and parameters
levels of representation
Occam's razor
modeling resolution
the importance of purpose and context
time dependence
bounds
lumped parameters
differences between deterministic and stochastic models
use of diagrams and schematics for formulation, solution, and explanation
identification and incorporation of constraints
designing and presenting models and solutions
solution estimation
the role of optimization
model verification and sensitivity analysis
how to compare models
representing and exploring trade-offs
qualitative and quantitative models
algorithm
heuristic
trade-offs
best change
state-of-the-art
rule of thumb
order of magnitude
factor of safety
resource allocation
risk control

The approach taken in the **How to model it** course is similar to an approach called "Problem-based learning." Problem-based learning was described by Barrows and Tamblyn[22] as follows:

> Problem-based learning is the learning that results from the process of working toward the understanding or resolution of a problem. The problem is encountered *first* in the learning process. There is nothing new about the use of problem solving as a method of learning in a variety of educational settings. Unlike what occurs in real-life situations, however, the problem usually is not given to the students first, as a stimulus for active learning. It usually is given to the student after he has been provided with facts or principles, either as an example of the importance of this knowledge or as an exercise in which the student can apply this knowledge [pp. 1-2]

Problem-based learning is very suitable for engineering (as it is for medicine, where it is currently used) because is helps students develop skills and confidence for formulating problems they've never seen before.

This is an important skill since few or no engineers are paid to formulate and solve problems that follow from the material presented in the chapter, and have a single "right" answer that one can find at the end of a book.

Learning Environment

What kind of environment helps students gain confidence and feel comfortable coming up with their own ideas? What can faculty do to create and foster this type of environment? Carefully structuring cooperative learning is one highly effective way of helping students learn how to struggle and work hard. A cooperative environment is one of openness and trust, one in which students are encouraged to speculate and innovate.

Formal cooperative learning groups are very effective for providing a safe and stimulating place to help students formulate and solve problems. When students work in cooperative problem-solving groups, these groups should be small--two to four members. Groups are best formed intentionally with the instructor either randomly or deliberately assigning students to groups. The groups stay together until the task is accomplished and then change with each new assignment. Typical problem-solving group work instructions are:

1. Groups formulate and solve problems. Each group places their formulation and solution on an overhead transparency or on paper, and ensures that each member understands and can explain it.

2. Randomly selected students are invited to present their group's model and solution.

3. Whole class or combinations of groups discuss variety of ways of formulating problem and the range of solutions. All members of the class are expected to discuss and question all models. The discussion alternates between whole class and small group.

4. Groups process their effectiveness in working together as a team.

5. Each group prepares and submits a homework assignment report.

A formal cooperative learning lesson template for a problem solving lesson and a sample lesson are given below.

Problem Solving Lesson Template

TASK: Solve the problem(s) correctly.

COOPERATIVE: One set of answers from the group, everyone has to agree, everyone has to be able to explain the strategies used to solve each problem.

EXPECTED CRITERIA FOR SUCCESS: Everyone must be able to explain the strategies used to solve each problem.

INDIVIDUAL ACCOUNTABILITY: One member from your group may be randomly chosen to explain (a) the answer and (b) how to solve each problem. Alternatively, use the simultaneous responding procedure of having each group member explain the group's answers to a member of another group.

EXPECTED BEHAVIORS: Active participating, checking, encouraging, and elaborating by all members.

INTERGROUP COOPERATION: Whenever it is helpful, check procedures, answers, and strategies with another group.

Sample Lesson: Dangling by a Wire?[23]

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Subject Area: Engineering, Modeling, and Problem Solving

Grade Level: College/High School. Some background in algebra, physics and materials is helpful for solving this problem. College students enjoy the challenge.

Instructional Objectives: The **academic objectives** are for students to develop skills for formulating equilibrium relationships and building models to solve problems. Additionally, they learn about materials engineering. The **teamwork skill** objective is for students to learn to probe to improve their depth of understanding.

Time Required: Approximately 45 minutes.

Lesson Summary

1. **Teacher Explanation to Whole Class:** In this problem we are going to use estimation and modeling to determine the smallest diameter steel wire that could support a 200 pound person.

2. **Small Group Task:** As a triad, students are to:

    a. Individually estimate the diameter of the smallest steel wire that would support a 200 pound person.
    b. Turn to the group and exchange estimates and strategies for determining a better answer.
    c. Create a model of the situation and prepare one answer for the group.
    d. Report to the whole class on the group's answer and model.

3. **Teacher Monitoring:** The teacher monitors to ensure that all students understand the assignment and are working skillfully.

4. **Simultaneous Explaining:** After 10 minutes students stop work, find a partner in an adjacent group, and explain their group's model for arriving at an answer.

5. **Whole Class Discussion:** A member of several different groups should be randomly selected to explain how their group solved the problem.

6. **Follow-Up:** Each group writes a report on how they solved the problem--the formulation of their model, including the assumptions, sensitivity of the model, and next steps.

Pre-Instructional Decisions

Group Size: Three.

Assignment to Group: Teacher assigned groups if enough time (and background information on students) available, otherwise random. Distribute students according to "bunge cording" experience.

Roles:

Recorder: Person in group who weighs the least. Recorder gets copy of problem and records group's answer and method. Group member on Recorder's right is the **Prober**. The prober asks for rationale and elaboration, and questions the group's assumptions, model, etc. The **Encourager** makes sure each group member participates in the process. Remember these roles are in addition to each person's responsibility to help the group solve the problem.

Materials: None required. Although pieces of fine steel wire and materials science textbooks are helpful.

Explaining Task and Cooperation

Task: "Individually estimate the diameter of the smallest steel wire that could a 200 pound person." "You have 60 seconds to make an individual estimate. Record your answer and the strategy you used to arrive at your answer. Volunteer your answer so we can determine the range of individual estimates."

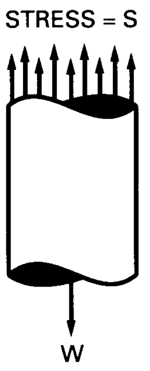
After 60 seconds, call for volunteers to give their estimate of the diameter. Record their answers. Often the range is quite large, from "the thickness of a hair" to one inch. Ask how a better answer could be found. Probe what quantities should determine how much load a wire can hold. Record the list of quantities. It will usually include: the material and the cross-sectional area of the wire.

"Join with your triad and make a joint estimate. You have ten minutes to do so. Develop a model to use for refining your estimate. Record your answer and your model."

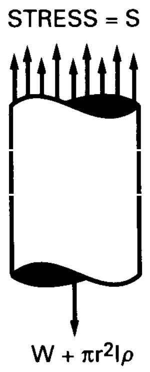
If (or when) students say they're done, ask them if they would be willing to hang by their wire from a helicopter hovering at 1,000 feet.

After 10-15 minutes ask students to stop working, find a partner in an adjacent group, and explain their group's answer and model.

After 5-10 minutes, ask the students to pause and randomly call on individuals to present their group's answer and method. Record the diameter and their method on the overhead.



Segment of weightless wire.



Segment of wire including weight.

Explore the relationship between the load and the cross-sectional area. The bigger the wire is, the more load it should be able to hold. The load in the wire divided by the cross-sectional area is called the stress in the wire. This stress is surprisingly constant across the area. By experimenting with various materials, we can find the stress that each can take without breaking, and the resulting values are referred to as breaking strengths, or failure stresses, of the materials. These quantities are not absolute, as different batches of the same material have some slight variation. But they are close enough to be usable by engineers.

The breaking strengths of various steels range from 60,000 pounds per square inch (psi) of area to 200,000 pounds per square inch. Let's assume that the steel wire we're using has a breaking strength of 100,000 psi (ascertained by calling the manufacturer, or testing a piece ourselves). Let's examine a little section at the top of the wire, and derive a relationship between the quantities of interest. At equilibrium, the forces pulling up on the wire must be the same as the forces pulling down (see figure). Furthermore, let's assume that the weight of the wire is very much less than our weight, so we will ignore it. The

$$sA = W,\ s = W/A,\ s = W/\pi r^2$$

equilibrium relationship tells us that
where s = stress = load/area; A = area (πr^2 for a circle); W = our weight.

For a breaking stress of 100,000 psi, and a load of 200 lbs, this relationship will tell us that for our example, the diameter is 0.05 inch, or slightly under 1/16 inch, since

$$d = 2r = 2\sqrt{\frac{W}{\pi s}}$$

Would you actually go out and hang by this wire? No way for me! First or all, any flaw in the wire or error in my assumptions would drop me from the helicopter. Second, I would worry about how steady a platform the helicopter was and how the attachments might weaken the wire. I would definitely want a safety factor. How big a safety factor would be a matter of judgment, since it would depend upon how much I value life, money, and so on. However, if I could design the attachment, if I trusted the weather and the helicopter pilot, and if the manufacturer assured me that the strength of the wire was at least 100,000 psi, I might be talked into hanging on a wire with a diameter of 1/8 inches, since the cross-sectional area would be about four times as large.

What steps would you take to refine your answer? For example, were we justified in ignoring the weight of the wire? Let us call the length of the wire *l* inches. Our relationship now becomes

$$s = (W + \pi r^2 \rho l)/A$$

(where ρ is the density of the wire. For steel $\rho = 0.283$ lbs/in^3.) Let us assume that our wire is 1/4 mile long. The diameter would have to be 0.052 inches. Not much change in diameter from before. We were probably all right in neglecting the weight of the wire.

Explore the effect of other assumptions and parameters. For example what would the diameter of an aluminum wire have to be, or what is the effect of acceleration (Could you jump out of the helicopter as with "bunge cording?").

Ask the students to summarize their major learning, and to think of similar situations where their learnings apply.

Criteria for Success: Sixty-second answer from each individual, and signed answer sheet from each group which contains smallest diameter steel wire and a description of their method.

Positive Interdependence: The **cooperative goal** is for triads to decide on one answer and model which all members can explain. The **intergroup goal** is for triads to check each other's work and provide any suggestions and assistance other triads need to obtain a better answer.

Individual Accountability:

1. Teacher observes each triad at work.
2. Partners check each other's work.
3. Another triad checks each triad's work.
4. Teacher randomly selects individual members of the groups to present.

Expected Behaviors: Everyone participates in group discussion. Each member of group can explain answer and method.

Intergroup Cooperation: Whenever it is helpful, check procedures, answers, and strategies with other groups.

Monitoring and Intervening

Monitoring: Circulate among the groups to check that everyone is participating and that roles are being followed (only one person recording, one person probing, and one person encouraging.) Monitor to catch misunderstanding in the early stages and to help establish the rules.

Intervening: Remind groups that both are expected to participate, and understand and be able to explain their formulation and solution. Model and coach checking by asking questions of randomly selected individuals.

Evaluating and Processing

Evaluating: Each student shares the triad's answer and model with a member of another triad.

Processing: Remind groups that every member has two functions: complete the task and maintain good working relationships. Ask groups to discuss effectiveness by individually listing two things that went well and one thing the group needs to work on. Whip around groups and list the things that went well and the things that need work.

Closure: Summarize the lesson. Discuss the key features of modeling--assumptions, representation, sensitivity, resolution (how good an answer is needed), etc.

Cooperative Learning

The five basic elements of a well-structured formal cooperative lesson are embedded in the sample problem solving lesson (Johnson, Johnson & Smith[24],[25]). **Positive interdependence** is structured in the cooperative goal--one set of answers from the group, everyone has to agree; and the cooperative umbrella is extended in the intergroup cooperation section. **Individual accountability/personal responsibility** is specified in its own category and is implied in the statement "everyone has to be able to explain the strategies used to solve each problem." **Face-to-face promotive interaction** is stressed in the expected behaviors section, especially "active participating." **Interpersonal skills** are emphasized in the expected behaviors section, especially "checking, encouraging, and elaborating." **Group processing** is structured by asking the groups to list two things their group is doing well working together, and one thing they can improve.

The power of the cooperative learning environment is amazing. Students formulate and solve difficult, practically interesting problems without complaining too much. They learn and grow through struggling with their peers. Why is this cooperative learning environment so effective? The overall research comparisons show that students learn more, remember it longer, develop superior reasoning and critical thinking skills, feel more support and acceptance, like the subject matter and the professor more (see Johnson, Johnson, & Smith for an extensive review of the literature). Some of the underlying rationale for these outcomes include:

1. Whoever organizes, summarizes, provides elaboration, justification, explanation, etc. learns. The person who does the intellectual work, especially the conceptual work learns the most.

2. More learning occurs in an environment of peer support and encouragement because students work harder and longer.

3. Students learn more when they're doing things they enjoy.

4. Learning that is informal, social, and focussed on meaningful problems helps create "insider knowledge." Gaining insider knowledge--learning to speak, write, and think engineering--is a major part of becoming a member of a community of practice[26].

There are two essential features to cooperative learning and problem solving--the groups they work in and the tasks they work on. Formal cooperative learning groups have been shown to be extremely effective for helping students learn, now lets explore the type of tasks or problems to give students. Do we give student the same old closed-ended, textbook problems that they've gotten every year? Not if you want to make the best use of their skills and talents, and prepare them for the real world!

Problem identification, problem formulation, and building models to predict, explain, understand, etc. are often neglected in most college courses, and is more important than solving problems. Albert Einstein wrote:

> The mere formulation of a problem is often far more essential than its solution, which may be a matter of mathematical or experimental skill. To raise new questions, new possibilities, to regard old problems from a new angle requires creative imagination and marks read advance in science.

It is the intellectual activity of building models to solve problems--an explicit activity of constructing or creating the qualitative or quantitative relationships--that helps the model builders understand, explain, predict, etc. The process of building models together in face-to-face interpersonal interaction results in learning that is difficult to achieve in any other way.

Learning in all disciplines involves constructing models, investigating ideas and developing problem-solving skills[27]. These activities are not limited to students in science and mathematics. They are shared by all who have a desire to understand, to interpret and to explain. However, the construction of mathematical and computer models is <u>central</u> to the activities of scientists, engineers and mathematicians, but is absent from most undergraduate curricula. Students' learning focuses on problem solving, but neglect problem finding and problem formulation.

Building models is an important activity for first-year students, since it mirrors the way engineers, scientists, and mathematicians work in the world, stimulates students' curiosity, and helps develop the confidence and competence. Ideas, materials, and problems have been used with high school students during summer honors college courses. Over ten years of experience teaching first year college students how to model convinces us that modeling is suitable for undergraduates. In fact, we feel it is essential for undergraduates!

Our most important objective is to develop students' motivation and skills for continued learning, problem solving and application of course material after the course is over. The general models of instruction proposed would assist in providing direction for getting students meaningfully involved in learning and focus attention on active learning to help prepare self-directed, autonomous learners.

According to Pat Cross[28], differences in student learning are due to teaching effectiveness. Effective learning depends on the performance of the students, not the teacher. It is an evocative process, not a performance. New information results in meaningful learning when it **connects** with what is already known. Ausubel said, "find out what a student knows and then teach accordingly." Catherine Fosnot[29] described the importance of active learning as follows:

> Teaching is never telling. . . real understanding is a case of active restructuring on the part of the learner. Restructuring occurs through engagement in problem posing as well as problem solving, inference making and investigation, resolving of contradictions, and reflecting. Learners need to be empowered to think and to learn for themselves. Thus, learning needs to be conceived of as something a learner does, not something that is done to a learner (p. 4).

Conclusions

The emphasis in this article on problem formulation and modeling is based on the observation that the world is moving too fast for experts, and old-fashioned "problem-solving" no longer works. Productive work has been moving away from problem solving toward whole-systems improvement as the secret for solving great handfuls of problems at once. Furthermore, effective work has been moving away from getting experts to fix systems toward having experts join everyone else in learning how to make improvements[30]. It is becoming clearer and clearer that knowledge and skill can't be pumped into people the way traditional schools have done it. They can be mastered only by applying theory directly on the job, to real problems, here and now. That requires the learner's direct involvement. Once again this change cries out for a different environment--one of cooperation, interdependence, and accountability. We learn and change as we have face-to-face contact with others and get new information. We change when we listen and respond in new ways, when we genuinely interact with others and when we listen to our inner voices.

The central question in deciding whether or not to ask students to do something in our classes is "When do we pass the torch"? Do we wait until they cross the stage during graduation to say "OK, take this torch, go forth and shed light." This appears to be the approach taken in most engineering programs. In my view it's too late and a great deal of time and energy is wasted. In our course "How to model it: Building models to solve engineering problems" we say, metaphorically, here is a little torch, "Go forth and explore, use your torch to shed some light on these problems."

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