The Pedagogy of Design

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Abstract

Contemporary society is characterized by an unprecedented rate of change. Such a high rate of change means that the development and application of knowledge under (new) problematic situations is what we do the most. A broad, and current, conception of engineering design includes methods for applying knowledge that are of great relevance for a range of human activities far wider than that usually covered by engineering design. It is suggested that pedagogy is one of those activities that can benefit greatly by being informed by design methods. Thus, we can prepare all students for a changing world by teaching them the norms and methods of design through a pedagogy which embraces those norms and methods. The theoretical and research support for such a pedagogy is also presented.

Social Change

Technology is one of the forces that drives social change, and it seems to be doing so at an increasing rate. It led to the transition from an agricultural economy to a manufacturing economy to a service economy. Now, with massive corporate re-engineering laying off hundreds of thousand of white collar workers, a new order may be emerging.[1] This time it is information technology that is the driving force.

Changing one's job more often is only part of the modern scene. Restructuring the organizations where people work is another. In a survey of 12,000 managers in 6 countries, Kanter found that 36-71% of the mangers said that there had been a major restructuring in the last two years.[2] The figure for the United States was 59%. And many of the managers in the United States responded affirmatively to questions whether there had been a reduction in employment (31%), or an internal expansion (26%), or a merger, divestiture, or acquisition (35%).[3] Regardless of whether we keep our jobs and or experience restructuring, our job descriptions change continuously. Information technology is the main reason for this as the half life of much of the software our work is embedded in seems to have a half life of barely a year.

Global forces also are immensely influential in changing our lives. Global economic competition has led to many changes in the nature of work.[4] The end of the Cold War and global penetration and integration of national economies have triggered many highly informed commentaries on the "twilight of sovereignty" thesis that nation states are rapidly losing their influence on people's lives.[5] Information technology is a key here, too, with the quantity of global messages and data flows increasing by many orders of magnitude over the last few decades.[6]

These changes, and many others relating to politics and social differentiation, create problematic situations wherein people need to get together to define the problems and to develop options for dealing with them - although they do not always react this way. Design, in the broad sense, then, is a profound constituent of our culture. Done well, it is of great value. And, if we want it to be done well, it should be taught and practiced in our educational institutions.

Educational Change

Massy and Zemsky have note that information technology based teaching and learning will grow very rapidly and change pedagogy profoundly. And it will do so "no matter what the response of traditional higher education institutions."[7] Up-to-date facts and information on almost any subject can be easily located and accessed through electronic networks, CDs, TV, phone-lines, print material, and radio. Add to that the fact that information multiplies at such an overwhelming rate today, it is difficult for even an 'expert' to stay current in more than a single aspect of his or her field. Thus, schools and colleges have lost considerable ground in their role as "gatekeepers" of knowledge. While many people have argued that teaching practices must change because lecturing is ineffective, the truth of the matter is that lectures are simply no longer a valuable commodity because there are so many other outlets where current information can be garnered.

A second trend which also reflects larger social trends, is the demand for a more "consumer oriented" approach to education. This requires shifting the focus of education from teaching to learning; from instructor to student. Curriculum content and methodologies which were once based on the expertise and preferences of the instructor, shift towards the needs and preferences of the learner. In its pure form, this trend would have students in the role of designer, researcher, and problem-solver, responsible for their own learning, and creating their own paths through course content. Instructors shift from a 'sage on the stage' to a 'guide on the side' as they help direct student inquiry, facilitate research and testing activities, and provide reflective feedback based on their own knowledge and expertise.

This trend towards a learner-centered curriculum is complicated by the fact that our student population is more diverse than ever before. This reflects national demographic trends, but it is also a positive consequence of making the path to higher education more accessible. If we accept that education should be consumer oriented, and if we accept that all students are different, we must begin to conceptualize a new pedagogy capable of developing the skills and knowledge of all students.

Key Shifts in Higher Education[8]

From	To
Degrees/credential	Competencies/certifying
Physical classrooms	Virtual classrooms
Teacher-focused	Learner-focused
Presentation mode	Discovery mode
Standardized content	Individualized content
Information is transmitted	Learning is facilitated
Autonomous work	Team work
Fixed calendar	Flexible calendar
Centralized organization	Disaggregated organization
Local population	Global population

Don Tapscott, (1995). *Learning in the Age of Networked Intelligence*. EDUCOM: Keynote address. Portland, Oregon.

Design

Nietsche once said that all philosophy heretofore had been biography. Perhaps the same is true of design "philosophers," since there is so much diversity among the approaches of those who write about design. Even limiting the discourse to engineering design, as we will, the diversity is extraordinary. Some variations are understandable: the technical texts on design in different fields of engineering differ as they face different problems and deploy different analytical tools and technologies. And industrial design addresses different aspects of a product than the original engineering design.[9]

The energy devoted to design, and the commentary about it, increased in the 1980s due to pressures from global competition.[10] Some of this design energy has spilled over into engineering education where efforts to add more (some) design to the curriculum have been in evidence since the late 1980s and are codified in the current ABET requirements.[11] This paper will adopt an approach to design that is less than a comprehensive statement, but more, we hope, than two biographies. We will take design to be problem solving activities that occur where human needs meets technological resources. Our focus is on those patterns of behavior that occur at this interface under the rubric of progressive design practices in the late twentieth century. As we do this we will be searching for transferable principles for general application to human problems that we will then be applied to pedagogy.

This progressive design movement is occurring, not because the prevailing paradigm has been a failure so much as because the competition has, by necessity, searched for and found better ways of doing things.[12] Even the educational correlate of technology, the engineering school, is slowly responding to change by reintroducing design and team work, and by beginning to wrestle with the importance of life-long learning (due to the falling half life of engineering skills), with the research support for problem-based education), and with the competitive threat posed by CD ROMs and the WWW. Education is often a trailing indicator of social change, but change is being forced upon engineering schools by economics, technology and industry. It is this progressive movement in the social relations of work that we are addressing as it relates to both design and to education.

In this progressive context, good design begins with designing the design team. The decisions made early in the design stage determine at least 70% of the costs of development, manufacture and use of a product according to a report by the National Research Council.1[3] Thus the way a design team is initially assembled is of great importance. The advent of concurrent engineering means creating product development teams that stay with the product through design, development and manufacturing. These teams have representatives from design, manufacturing, marketing and key areas for the particular product. The teams should be characterized by breadth of relevant expertise and members with high cognizance levels - awareness of what is needed to be known and who should be consulted. Engineering consists of two great transformations: that of society and that of the environment. As Stefano Marzano, who heads Philips Corporate Design, noted in 1993, "Design is a political act. Every time we design a product we are making a statement about the direction the world will move in....We must be aware of our power." [14] The late departed Office of Technology Assessment, which advised on design at the rarified level of national policy, was outstanding at finding and consulting with all the stakeholders with respect to a given technology. The design team members need training in cooperative behavior and an incentive system which rewards cooperative behavior. It is also important that the design team has the support of the larger organization and adequate resources: institutional respect and support.

The first task for the design team is to discuss the adequacy of its make up and to recognize that needs for new members may emerge later. Then comes the task of problem clarification.[15] The design process is replete with neat ideas and personal causes that need to be controlled by constant recourse to the design problem itself (and by the norms of the group). This problem may well get changed by the client or the design team at several points in the design and product development process, but it is important never to lose sight of its centrality to the mission and the need to have the design problem clearly delineated. It is also at this stage that broad constraints of resources, cost, safety, and environment are first laid out - as are the project schedules (e.g., Gantt and Pert charts).

The next stage in the design process is the idea generation process. There is some evidence that this may be most productive if done by individuals and then brought to a brainstorming session.[16] Certainly the development of any product design will best be done with open and positive group collaborations.

Once a series of promising alternatives has been identified the selection process begins with a systematic weighing of tradeoffs. This may also be done by weighting each option's value for the customer needs and for the design criteria in matrix fashion.[17] (Fox, 1993; Cross, 1994; Ulrich and Eppinger, 1995) or algebraically by summing variables with a variety of weights.[18] It is important to look downstream and include criteria for cost and ease of manufacturing, ease of assembly, ease of use, and cost of disposal. And design for assembly converts readily into design for disassembly, a green design concept that is gaining more prominence both for reducing the waste stream and for ease of maintenance.[19] Once a selection is made the design needs to be developed with drawings, details, and specifications in a process that Pahl and Beitz refer to as embodiment.[20]

The next desirable step is rapid prototyping to test one or more of the possibilities. This will require resources from the parent organization, venture capital, or some state or federal program (technology transfer or small business focus) and as such it will constitute the first test of the design team's work. Some design is routinized enough that the prototyping stage is limited or skipped on the premise that the technology involved is well established. But competitive pressures are raising the salience of the innovative processes in design.

After this comes the ramping up for production which entails the industrial design that has much to do with the final look of the product. A design and development team might well oversee this process, also, since it will be affected by customer needs.

The above process can be, and has been, broken down into much more detail and illustrated with case studies. However, the further commentary here will be restricted to two points. Design is highly iterative from almost any point back to almost any point.

Second, group norms should support open discourse, high cognizance levels, celebration of diversity (ideational and social), commitment to learning, synthesis, empirical inquiry and experimentation, soft leadership, cooperative relations, and good project management skills.[21] It is particularly important to recognize that design involves an inquiry driven learning process whereby the team will learn about the problem, about the needs of the stakeholders, and about the wide variety of information and skills needed for solutions to that particular problem.

A Pedagogy of Design

The characteristics of design, as outlined above, may be applied to a range of situations in which individuals face problems. In education we may construct a pedagogy based on many of these characteristics that would prepare students well for a life of change. In short, such a pedagogy will look like project/problem based learning, and there is research support for the enduring effects of such curricula being better than those of more traditional approaches. First, we will discuss some of the theoretical justifications for moving to an active, group, iterative, open-ended, inter-disciplinary curriculum that is based on a project that imbues all the learning with meaning and relevance.

New pedagogical mandates to emphasize processes over isolated facts, to center learning around authentic problems, to encourage trial and error, and to appreciate the diversity of talents that different individuals bring to a project, are not simply reflections of larger societal trends. In fact, there is evidence that such techniques and perspectives comprise a viable instructional methodology.

Cognitive scientists and psychologists have forged their own rationale for such pedagogical practices that is supported by a cumulative body of research on how the brain works. What follows is a summary of principles and conclusions that have been extracted from this research. In addition, we also attempt to illustrate how these principles lend themselves in support of a learning methodology situated in the practice of design.

A. *Researchers agree that the search for meaning is innate, survival-oriented and basic to the human brain.* Furthermore, the search for meaning is at the heart of intrinsic motivation. Much of the drive to engage in essential tasks comes from the brain's search for meaning.[22]

Implications: Learning should be situated in problem-solving, and meaning-making activities. Problem-based learning imposes a cognitive dissonance that is requisite to intrinsic motivation. Fittingly, the design process begins with the identification and definition of a problem. The learner attempts to define the void that exists between "what is" and "what should be." Once defined, the learner can then attempt to fill this void by fashioning an appropriate solution.

B. *Cognitive structures --which reflect knowledge structures-- are flexible.* They change in scope, structure, and complexity as we encounter new instances of the same information, and as we form cognitive connections among related information.

Implications: In any domain of knowledge, deep understanding requires that skills and information are acquired and applied in multiple contexts; and that problems are explored from multiple perspectives.

Spiro et. al.[23] coined the term "cognitive flexibility" to describe how our understanding of any given concept is dynamic --expanding and changing with every new encounter with the concept. Thus, deep understanding of a concept --or of a domain of information-- requires repeated encounters, in multiple contexts from multiple perspectives.

The process of design supports cognitive flexibility in two ways. First, the iterative nature of the process forces the student (and the engineer) to continually revisit each aspect of his or her design and reevaluate the solution against the criteria defined in the problem statement. Each time an adjustment is made, the student analyzes not only the effects of the incremental change, but must reevaluate the entire system. Second, throughout a semester (or throughout a sequence of courses), students should be asked to solve many problems of a similar nature in varied contexts --problems which call for similar rules, tools, and skills to be applied in new ways. Each new problem case adds to the student's "flexible" understanding of how specific rules and skills can be applied and generalized across contexts.

C. *Learning occurs through the meaningful organization, categorization, and accommodation of information into one's existing knowledge structure*. Feedback, the result of cognitive dissonance, drives this process. The brain is designed to perceive and generate patterns and resists having meaningless patterns imposed on it. Initial cognitive structures will re-organize themselves to accommodate otherwise meaningless patterns.[24] This is learning in the most precise way it can be conceptualized --actually changing one's cognitive structure.

Implications: The attainment of any learning goal should involve an iterative process; a process with many opportunities for creation, reflection, and integration of feedback through modification and revision. This is accomplished by putting one's ideas 'out there' for scrutiny, testing them for integrity, or comparing them against established standards. We do this by translating a design that exists in our mind's eye into an articulated hypothesis, a draft blue print, a tangible structure, or a written document. Through this process learners are able to receive feedback, and revise, modify and adapt their ideas accordingly. This is the core of the design process. Meaningful feedback should come from a variety sources, starting with those who have a stake in the outcome or integrity of the project: the learner/designer, team members, colleagues, project benefactors/customers, scientific experts, industry experts, and other's impacted by the project.

D. *We understand best when facts and skills are embedded in natural memory --actual networks of information which allow us to retrieve information and integrate new facts and concepts.* This memory system is inexhaustible and is enriched over time as we increase the items, categories, and procedures that we experience.[25]

Implications: In order for new knowledge to become embedded in natural memory, learning must be embedded in authentic tasks. When information is taught in isolation, it forms weak and remote connections to one's existing knowledge schema. However, when information is learned in an authentic setting, it forms multiple, direct connections to all the familiar aspects of the learning experience. For example, memorizing an equation for calculating optimal wing span of an aircraft has weak associations to any part of our natural memory. However, if the equation is learned and applied in the context of designing one's own aircraft, testing the aircraft performance, analyzing the effect of wing span on performance, and modifying formula variables to derive a new optimal wing span,...the new knowledge now has several direct connections with various aspects of the aircraft design process. Next time the skill (calculating wing span) is used in its authentic context, it will be much easier to retrieve.

Authenticity of task is also directly related to perceived relevance, which has been shown to have great bearing on learner motivation.[26]

E. *Each brain is unique and each individual has a unique composition of various types of intelligence* .[27] Although we all have the same set of biological and neurological systems, they are integrated differently in every brain. In addition, because learning actually changes the structure of the brain, the more we learn, the more unique we become.[28]

Implications: Stakeholders each have something unique to contribute to a design project. This is because each person envisions and assesses the project a little differently --through their own experiences, knowledge, and interests. Thus, projects are greatly enhanced through cooperative team efforts.

Consider the concerns of the following professionals in regard to the design of a bicycle:

Exercise Physiologist - "How does the size of the gear cogs affect a rider's average cadence and the rate at which glucose is burned?"
Material Scientist - "How can composite materials be used to minimize the weight of the bicycle?"
Industrial Designer - "Which aspects of the bicycle's ergonomic design can be made adjustable?"
Marketing Specialist - "What are the principle features that will cause a bicycle owner to upgrade to this newer model?"
Cyclist - "Does this bike have the best combination of features I need for the money I am willing to spend?"

Exhibit 1 summarizes the implications of cognitive psychology research (presented above) on pedagogical methods. Each principle is referenced with the letter A - E.

Exhibit 1: Implications of Findings in Cognitive Psychology on Pedagogical Methods

	least desirable <---		> most desirable
A.	• no problem to solve	• problem has a singular, definitive answer	• problem is novel and has many possible solutions
B.	• context is singular • perspective is imposed	• several contexts are explored • multiple perspectives are imposed	• several contexts are explored • multiple perspectives are offered • learner is encouraged to articulate own perspective
C.	• learning & project development process is linear • project has fixed start and end points	• learning & development processes are iterative • start & end points, as well as milestones, are fixed	• learning & development processes are iterative • start & end points are determined by project parameters
D.	• non-authentic goals • no accountability	• goals are authentic • accountability is simulated	• goals are authentic • accountability is to an actual client, or group of stakeholders
E.	• analysis and solution come from a single person, a single perspective	• analysis	• analysis, solutions, and discussion of implications come from many people, many stakeholders, many perspectives.

Part IV. Designing the Design Curriculum

How do the various philosophical arguments, social mandates, and learning research presented above come together as a cohesive pedagogy having functional application? The following section begins to address some of the necessary considerations for designing a design curriculum. The perspectives and research presented above do not, in and of themselves, provide a tight framework around which to design a design curriculum. Instead, this compilation of ideas and strategies should be woven throughout a curriculum, and can provide a reference against which to check the integrity of curriculum activities.

A well-developed foundation of literature on problem-based learning and case-based learning exists in content domains such as business, economics, and especially in medical education.[29] Much can be learned from models developed in these domains. The practice of engineering, however, necessitates a slightly different approach. The goals of the former disciplines are to derive an optimal strategy or diagnosis that will then be applied. There is little opportunity to test one's solution, learn from authentic feedback, and revise one's solution accordingly. In medical education, such testing represents an ethical conflict, and in economics and business, outcomes can usually only be assessed in the long term. Thus, a different framework is required for engineering, which includes both problems and cases in the form of authentic design projects and prototype development and testing. Thus, the approach we suggest is referred to as *project-based learning*.

Project-based learning, in its most simplistic form includes: 1) an authentic problem to be solved; 2) multiple solutions that can be expressed in some tangible form, such as a CAD model, a prototype model or to-scale structure, or a detailed design blue print; and 3) a rigorous and iterative design process driven by stakeholder considerations, prototype testing, and revision. A team approach, and access to a rich body of information and feedback resources are also critical.

Frameworks for guiding and assessing the validity, authenticity, and integrity of problem-based curricula been also been offered.[30] Again, a project-based curriculum in engineering design requires additional methodologies which will facilitate the acquisition of design as a process, as well as the design and development of a feasible product outcome. We are concurrently addressing these issues to be presented in another paper, but it is worthwhile to briefly describe the high-level considerations (outlined in Exhibit 2).

The considerations presented in Exhibit 2 reveal their importance as one contemplates the necessary congruence among education goals, the resources required to reach those goals, processes which enable the goals, and ways in which the goals are measured. Many organizations set out to implement problem-based learning without considering how various other aspects of the learning environment must also be re-organized and re-designed to ensure successful implementation. Exhibit 2 attempts to illustrate this. For example, learning outcomes cannot be changed without also considering how learning processes must change to produce these outcomes. Likewise, new outcomes will necessitate new ways of evaluating learning.

When it comes to evaluation, the framework presented below will prove insufficient for many readers. What good is a new paradigm of learning unless it yields desired outcomes? This is a valid concern that we will first address by paraphrasing Tempelaar who states that a key prerequisite of any assessment system, whether problem-based or not, is that its procedures are congruent with the educational and instructional principles.[31] Students, as well as instructors, adapt their approach to the assessment procedures in order to maximize their success. One of the driving forces behind a project-based curriculum (which we have attempted to lay out in the preceding sections of this paper) is that it is congruent with not only cognitive and educational principles but with norms of engineering practice and societal trends. It shift emphasis from memorization of de-contextualized facts and formulas to deep conceptual understanding applied through the process of design. It moves students from isolated, inauthentic tasks to complex solution design for real problems embedded in their social context. It moves students from the novice to the journeyman status of design. (Arguably, expert status is achieved after extensive experience in the field).

In terms of empirical evidence, while more studies are desirable, the research that is available on the effects of problem-based, practice-based, and case-based learning offers promising results. For example, Hmelo found significant increases in 'hypothesis-driven reasoning' (a desirable outcome) for students participating in a problem-based learning curriculum in medical education over their traditional counterparts.[32] She found similar results for other knowledge and reasoning strategies including 'coherence of explanations', 'accuracy of causal models', and 'use of science knowledge'. Others have reported that implementation of case-based learning is especially successful for complex, and ill-structured domains.[33] And industry employers wholly support an increased emphasis on authenticity of learning, applied learning, and the development of teamwork skills, as these critical skills are currently deficient among many new engineers

Conclusion

The authors believe that design offers a model for pedagogy that is very promising not only for engineering students but for students in all majors. And the key to this pedagogy is project-based learning. Responses from readers are very welcome.

Exhibit 2: Considerations in the Development of a Project-Based Curriculum

Consideration	Dimension	Curriculum Design Questions
Defining Curriculum Goals for Project-Based Learning	a. Learning outcomes	• What skills and knowledge are required of students? • How will required learning outcomes be assessed for individuals and groups?
	b. Process outcomes	• What will be the expected protocol for team work? • How will teams demonstrate their use of the design process: problem clarification, stakeholder identification, concept generation and selection, prototype development and testing? • How will teams demonstrate their learning progress and evolution of ideas, identification and use of resources, and of learning how to learn?
	c. Project outcomes	• What projects can be designed that will encompass the knowledge, skills, and processes specified above. What makes a good design good?
Specifying Resource Requirements	a. Required resources	• What tools, materials and resources are required to carry out the project activities?
	b. Multiplicity of resources	• Are identified resources authentic, reflecting those currently used in engineering settings? • Are identified resources diverse in nature and in media format? • Have non-traditional resources been considered, if relevant, i.e., those usually overlooked for classroom use?
Impact on Stakeholder Roles	a. Instructor's role	• What will be the instructor's role in helping students achieve course outcomes, providing feedback, locating resources, and evaluating learning?
	b. Student's role	• What will be the required/expected role of the student in achieving course outcomes, seeking feedback, locating resources, helping teammates, and evaluating their learning?
	c. Societal stakeholders	• What will be the role of potential employers and future stakeholders in the design process?
Evaluating Project-Based Learning	a. Evaluation as a learned process, as opposed to a culminating, terminal event only applied to the students	• How will evaluation activities be embedded in the deign process? • How will students be cued to use evaluation as a source of feedback from which they can learn and improve their design?
	b. Sources of evaluative feedback	• Have multiple and authentic sources of evaluative feedback been made available to students?
	c. Evaluate various outcomes	• How will learning outcomes be evaluated? • How will project outcomes be evaluated? • How will process outcomes be evaluated?

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