Designing and learning: a disjunction in contexts

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Two ideologies about engineering, one claimed the habit of engineering design practitioners, the other that of engineering educators, are advanced. The two are incompatible. The disjunction is elaborated in terms of two distinct postulates and their consequences. A remedy for educators is recommended and the experiences of the author in attempting to change the context of learning to better accord with engineering practice are described.

Keywords: design education, engineering design, design problems

For the past decade, I have been engaged in a task, funded by the National Science Foundation, aimed at renovating undergraduate engineering education. This has been a collaborative effort involving faculty, staff and students of seven schools and colleges of engineering in the US. Design—engineering design—has been the defining feature of our ECSEL coalition's program of reform.

Our strategy was not intended solely, or even mainly, to improve the teaching of design per se, although new courses were developed to do just that, but rather we sought more fundamental change in the whole of the student's learning experience, a change captured in our original intention to 'integrate design throughout the curriculum' (later shortened to 'learning by design'). We were motivated by the not uncommon complaint that engineering education had over-invested in analytical technique and scientific understanding at the expense of the practical, 'hands-on', the creative, the reflective, the social, the constructive, the ethical, the economic—all those dimensions spanning engineering design space.

I am not going to report on the ECSEL venture here—that I have done elsewhere[1]—nor am I going to attempt an analysis of why this complaint is made or from whence it came—as has been conjectured elsewhere[2] and

1 Bucciarelli, L L, Einstein, H, Terenzini, P and Walser, A 'ECSEL/MIT engineering education workshop : A report with recommendations' *ASEE Journal of Engineering Education* Vol 89 No 2000 (1999) 89

2 Bucciarelli, L L and Kuhn, S 'Engineering education and engineering praciice: improving the fit' in **S Barley and J Orr** (eds) *Between craft and sciences: technical workers in US settings*, Cornell University Press, New York (1997) pp 210–229

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as others have analyzed more thoroughly[3]. Rather here I put forward a way of understanding this complaint as symptomatic of a fundamental disjunction between the way professionals see and experience engineering practice and the way academics see and experience engineering education, a disjunction evident only if one looks broadly at both domains giving full attention to context, whether that be the process engaged by practitioners designing or the process engaged by faculty in teaching—as well as to content, the methods and products used and produced in practice or the topics and methods covered and exercised in the classroom.

I attempt to capture the difference in the nature of design process and that of educational process in as crisp and succinct way as possible, in the form of two fundamental postulates about the essence of engineering, one which I claim defines the perspective of those doing engineering design and another, the perspective of those doing engineering education. They may be taken as the basis of the implicit understanding of practitioners in both spheres—engineering design and engineering teaching—of what they are about. After an elaboration of the two visions (or ideologies), I describe briefly how we attempted, with some success, to set matters right, i.e. to renovate undergraduate engineering education to better match the needs of engineering practice. I hold that it is the practitioner's way of seeing and experiencing engineering that is the 'correct' vision; it is the faculty's ideology which is off.

1 *Two postulates*

The postulate defining engineering design:

Engineering design is a social process requiring the participation of different individuals having different competencies, responsibilities and technical interests. Each participant sees the object of design differently, in accord with the paradigmatic core of their discipline, and their position of responsibility.

The postulate defining engineering education:

Engineering is an instrumental process requiring the application of established, rational scientific theory in the development of new products and systems for the benefit of humankind. Different engineering disciplines rest upon different paradigmatic sciences.

We could, at this point, compare these two statements alone; both likenesses and differences are apparent in their constituent elements, but the full force of the disjunction I am trying to construct only becomes apparent

3 **Seely, B E** 'Research, education, and science in American engineering colleges, 1900-1960' *Technology and Culture* Vol 34 No 3 (1993) 344–386

with further development of the consequences which follow in their wake. To proceed in this, I take each in turn, starting with engineering design process.

2 *Engineering design—in the throes of the social*

Again, the postulate:

Engineering design is a social process requiring the participation of different individuals having different competencies, responsibilities and technical interests. Each participant sees the object of design differently, in accord with the paradigmatic core of their discipline, and their position of responsibility.

The claim that designing is the business of a group of individuals, a team, will be accepted by most of those who have an interest in our subject. But the notion that different individuals 'see' the design differently (at any stage in the process) requires elaboration I suspect. What I mean is that each participant, responsible for some particular sub-function or subsystem of the design, works within a particular technical domain—that of their particular competence—and the ways of modeling, thinking about the design, the questions one raises, the way they are framed, the resources one has to call into play in response, all of this is in accord with the paradigmatic technique which provides the basis for thought and practice within that world and differs from that of another participant. I say that different individuals work within different object-worlds. There is one object of design, but different object worlds[4].

Within these worlds, rational, instrumental thinking is the norm. Here analytical modeling, well founded approximation and tried and true heuristics govern the way one sees, interprets and represents the object of design and its behavior. Quantitative values prevail, fixing the magnitude of 'inputs' or independent variables and 'outputs' or dependent variables. A structural engineer, sees the object as a frame (or a shell, or truss, or beam). He or she sees and estimates the anticipated loading due to weight or shock or vibration or thermal gradients—whatever external factors may be taken as cause—and calculates the displacements of the object-as-structure and the internal stresses and where they are likely to exceed a maximum allowed. An electrical engineer may look at the same object of design and see only the electronic functioning of components embedded in the structure. Another world, another way of modeling, other variables, questions, metaphors, tests, etc.

4 **Bucciarelli, L L** Designing engineers MIT Press, Cambridge, Massachusetts (1994)

If one accepts this postulate as a characteristic and defining feature of design process, then other claims are possible, if not direct consequences:

No participant has, at any stage in the process, a comprehensive, all-encompassing understanding of the design. No participant has a 'god's eye view' of the design.

When researching design process through participant/observation in the firm, I would often ask different individuals, in the wake of a formal or informal meeting, what was significant that happened or why a particular decision was made. I was usually given different, significantly different, explanations of what transpired. Having some experience as a historian of science, my anxiety was transient: I knew that a historian's report depended upon, not only his or her competence and the source materials that were accessible, but also upon his or her interests and beliefs about what really mattered, what was worth marking as historical. I concluded that while each participant had a vision of what was going on, what the state of the design was at any particular time, there was no one story that contained all the insight and significant information offered by the ensemble.

Note that it would be a mistake to try to force these into agreement, to construct a single story, as the historian is prone to do. One would have to discount, if not neglect entirely, those bits of the reports of different participants which differed. One could, if one chooses, avoid this problem altogether by never seeking participants' views and focusing only on the product of design, after the fact of design, and figure out from the way it works why the handle was put in this position, why the state logic was laid out the way it was, why the power supply was chosen as such, etc. This would constitute a rational story but ought never to be taken as an adequate, thick description of decision-making in designing.

One who studies design process will never have a comprehensive and all-encompassing set of all significant data.

Early on in my field study, I often wondered if I had access to all significant events, documents, meetings formal and informal, exchanges with corporate headquarters and other higher-ups, and the like. I deemed that I did not. I eventually came to terms with this deficiency in ethnographic method: I reasoned that if I believed that I had gained as 'valid' an understanding of what was going on (or had gone on) in the design process as any randomly chosen participant at any randomly chosen time in the process, this was sufficient. Indeed, if one agrees with the first consequence of the postulate, it would be self-deceiving to claim anything more.

While object-world work may be taken as instrumental (e.g. one can optimize) and rational in an analytical sense, there is no corresponding *analytical basis or method for reconciling and harmonizing the claims, demands and proposals of different participants.*

This requires an addition to our fundamental postulate, namely that:

The design task can not be fully disaggregated, broken up, or reduced to subtasks that can be independently pursued.

This is not to say that normative, prescriptive methods, or algorithmic, analytical procedures, constructed in an attempt to resolve trade-offs, achieve consensus in concept selection, or to optimize the design and the like are not without merit nor value. Rather the point here is that these methods and structures do not work as say, a finite element analysis works, or a block diagram of a control system works.

What they *do* do is fix a framework for discussion and negotiation across object worlds. As such they do have value and can be useful, but only if they are admitted into the process as methods to be manipulated, shaped for the immediate purpose at hand, even ignored if that proves most useful.

The design is 'under-determined' in the sense that all possible 'behaviors' (i.e. functionings, workings, states, input-output response) are never fully determined or forecast in the course of the design process

The reference for 'determined' here is the analytical rigor of object-world deduction and prediction. Even within object worlds there are limits to predictability due, in part, to lack of resources e.g. time, or inability to fully replicate the context of use. Then too, some 'inputs' are difficult to capture in an analytical model. How does one model the quality of maintenance? There are parameters, difficult to quantify, their range uncertain. While these can be dealt with probabilistically, there are other parameters which remain unknown: i.e. designing and product development often reveals new behaviors that lead to adjustments and modification in theory or heuristics. These often emerge in testing of a prototype or bench top experiment. If these confrontations with hardware are not done, if serendipity is not given the opportunity to rear its helpful head, then a feature or bug remains hidden-potential and there to show up in use once the product is launched.

But perhaps the more potentially problematic expression of under-determinedness derives from the unanticipated interaction among the design contributions of different object world work. According to the fundamental postulate, it is difficult to analytically represent, and hence predict, all the interactions across the interfaces among object-worlds. Analytical exactness and completeness may hold within the world of the structural engineer—her model may very well predict within 10% the actual displacement of the structure but the connections among structural behavior and electrical behavior appears loose, indeed, non-existent—until the unanticipated interaction causes failure.

This query is meant to counter the naive view of engineering design as the straight forward, rational application of science, of instrumental reasoning—a presumption of the public and evidenced by those who strive to make design a science. There is indeed a resonance here with science—in the philosophical position that holds that one can never fully verify a theory.

3 Engineering education—in the wake of science

Again, the postulate:

Engineering is an instrumental process requiring the application of established, rational scientific theory in the development of new products and systems for the benefit of humankind. Different engineering disciplines rest upon different paradigmatic sciences.

This may be taken as the basic belief which girds the planning of curriculum, the choice of subject matter, the resources deployed by faculty and put to use by students. The statement itself makes no reference to who it is that engages in engineering processes or to the contexts within which engineering takes place. Of course engineers work in a wide variety of contexts—scientific, as in a laboratory; financial, as on Wall Street; managerial, as they work their way up in a firm; and not an insignificant number of students may go on into law or medicine. This tenet shows little awareness of the different professional paths our graduates may embark upon; yet an argument can be made that science and analytical reasoning provide the best preparation for life in all of these lanes—if one buys into the priority of science.

I note too that while there is not a one-to-one mapping of specific sciences to specific departments; e.g. students in mechanical engineering study electronics and controls within a 'Mechatronics' option as do their peers in electrical engineering; and departments of Mechanical Engineering, Civil Engineering, and Aerospace Engineering all require 'Strength of Materials' or some such course based upon the theory of an elastic continuum; still, different varieties and versions of different sciences form the core of different departments—and these differences are defended when proposals are made by Deans anxious to avoid duplication of effort and to lower ‘costs of delivery’.

If we accept this postulate as defining the way engineering educators envision engineering practice, then certain characteristics of engineering education are readily explained.

Because well established scientific theories structure the curriculum and define the content of individual courses, individual faculty can claim a ‘god’s eye view’ and command complete control of the content of the course they are responsible for.

Faculty control extends over the selection of a textbook, the drafting of problem sets, quizzes and exams, the choice of conventions and symbol systems, sometimes even of units. In crafting a syllabus, faculty decide what is important to include, and what can be safely neglected.

But more significant is the way in which faculty give shape to scientific theory applied to problem solving: Presentation of theory aimed at application proceeds in a linear, deductive manner starting from as sparse a set of assumptions and fundamental concepts and principles as possible. The sense one gets with every new extension of theory is that there is no problem which will not yield, no phenomenon left unexplained at the end of the syllabus—none within the subject domain that might count at any rate.

The perspective of faculty is sacred; one does not question authority in an engineering science subject or core course within a departmental major. Fundamental concepts, no matter how mystifying are to be accepted as true and valid without question, though the history of science may reveal their articulation required considerable effort and what we now would judge to be misguided thinking. The emphasis is pragmatic, on use of theory in the solution of (well-posed) problems; attending to history is a luxury one can not afford.

As a corollary, students see little connection among courses. Unless faculty within a department or those responsible for prerequisites discuss themes and threads (symbol systems, common concepts and methods) that intersect in their different courses—a rare event in my experience—each course appears to students as an island apart from the others.

Note: While the organization and management within a school of engineering is not of concern here, I observe that the compounding of courses—which a departmental curriculum make—is just one aspect of the vertical structure which has prevailed within the university. Research groups within a department are sectioned in line with the blocks of courses that altogether define the major. Divisions within a department as well as the departments within the school are like ‘silos’, standing and functioning independent one from another. (This may be changing due to changes in funding patterns and the federal government’s interest in supporting centers of excellence and collaboration among departments focused on new technologies and techniques which require interdisciplinary effort).

The student experience is highly reductive, analytic; problems engaged have unique solutions.

In lectures, students are meant to take notes of all of significance voiced by the lecturer and written out on the board. The symbols and relationships unfurling in front repeat the theory and illustrate exemplars, perhaps found in the textbook, but embellished and massaged into a shape congenial to the faculty in charge. The narrative is analytic; language is specialized; although it sounds like English, the meaning of even ordinary words (e.g. continuity, stress, strain, displacement, force, mass, resistance, capacitance, circuit) must be constructed anew. This is done through the solving of problems—problems assigned, on quizzes, on the final exam.

The problems are of a very special sort: Unlike design opportunities, they admit of but one solution, and usually there is but one method to get there, to obtain the right answer. The student must see through the ordinary English language statement of the problem and grasp the analytical core the narrative points toward. Constructing exercises of this nature is quite a challenge: One generally includes only information relevant to the method or the principle the problem is intended to illustrate. There is no attention to context that has any depth, no elaboration of a scenario or situation where a practicing engineer might actually encounter a problem of this sort. Ambiguity and uncertainty are to avoided. Required ‘givens’ are specified as precisely as possible without giving away the answer and, likewise, acceptable answers are expressed in cryptic, symbolic or numerical form. Evaluation of the student’s work is correspondingly relatively straight forward although a conscientious grader may take the time to determine at what step ‘the student went wrong’. The phrase ‘under-determination’ has no meaning here.

The student learning experience is an individual experience; students are judged in competition with peers.

In most courses, in the core science-based courses, the student as individual is responsible for doing the work. Exams test individual learning. Even homework is generally expected to be independently addressed. While students may be allowed, even encouraged to learn from one another, what is graded are the productions of the student working alone.

That this is the case is related to the assumed objective nature of scientific knowledge—a form of knowledge seen standing apart from human inclination or temperament, never a matter of opinion nor style, and accessible to all regardless of race, creed or ethnicity—as long as they have mastered the prerequisites. It should look the same to everyone, hence there is little question about what constitutes knowing or, more specifically, what should be set as objective standards of achievement for each and every individual.

Some courses, e.g. a senior, capstone design course, may have students attack a problem in teams. But even here, the thrust is to figure out how to give a grade to each individual student. And here setting equitable standards becomes problematic.

Knowledge is like a material substance, a substance which faculty transmit to students.

The sciences that engineers apply are well established. Although there is considerable interest and excitement in frontier technologies (e.g. quantum computing, nano technologies), undergraduate engineering students study what is contained in well established textbooks. The sciences developed there date back one or two centuries. As such, the scientific knowledge that faculty teach is frozen, lifeless, unquestionable. It is knowledge in its canonical form.

Knowledge considered in this way is aptly suited for distribution by the all-knowing faculty to his or her receptive and passive students. At times it may be overdone; students complain its like taking a drink from a fire hydrant and even faculty may concede that they have chosen 'too much material to cover' on occasion.

Knowledge as material is static, distributed by faculty, read up on in a textbook, stored in memory to be recalled at the time of the exam. Knowledge lies outside, stands on its own independent of any particular context, never considered as an active, creative production of the moment.

A caveat: What I have described is the learning experience in the main, the dominating essence of the intellectual life of an engineering undergraduate. Of course, it is not all of this nature: Students engage in a wide variety of other types of stimulating projects, activities and programs. Think of the competitive design courses and projects—some nation wide, think of the service activities many students undertake, think of the independent research opportunities more and more universities are making available to undergraduates, and students take other subjects of contrasting nature in the Humanities, Arts, and Social Sciences, though the latter can be just as instrumental and abstract as their engineering core courses. Still I describe not a strawman; the fundamental postulate defines for most faculty the ideological basis for engineering education.

4 *Redress*

What we have here are two distinct perspectives, two different ideologies of engineering essence, one bringing to the fore the social nature, the other content, almost totally focused on the scientific. The disjunction between the two is clear; they even appear at cross-purposes. To redress, transcend and resolve the disjunction requires a new mix, new reflection, an altered perspective. That was the nature of our ECSEL coalition's challenge.

The challenge we faced is illustrated succinctly by a quote of a Dean of Engineering reported in *Leaders' Perspectives on a Decade of Change in Engineering Education*:

> Engineering educators are not trained or used to doing non-technical things in their educational spheres. Therefore, it's often left to others from other colleges or other disciplines, including retirees and industrial visitors, to help. There's only a small minority of engineering professors, for example who would want to teach a course in entrepreneurship or ethics... And the approach being pushed by ABET is to incorporate these non-technical things-to infuse them-into the curriculum. Even that's not easy. You go to a person, a faculty member teaching electromagnetics and Maxwell's equations and say, 'Put some ethics into your course.' And he or she is going to look at you like you're crazy. That's a problem.[5]

To illustrate our strategy, I sketch out how a traditional exercise of the sort encountered in an undergraduate engineering science course (in engineering mechanics but labeled 'Mechanics and materials' or 'Solid mechanics') can be transformed, transmuted into a task that embodies the notion that engineering is about creative exchange and negotiating meaning within a social milieu, about uncertainty and ambiguity and multiple framings, approaches and conclusions as much as about solving for the forces or displacements in a complex or simple structure.

This transformation is all about context. The content, in the sense that the main object of the exercise, the concept and principles one is trying to

5 **Bjorklund, S A and Colbeck, C L** 'The view from the top: leaders' perspectives on a decade of change in engineering education' *ASEE Journal of Engineering Education* Vol 90 (2001) 13–20

teach, to ‘get across’ to the student, remains the same—how force and moment equilibrium requirements enable one to find internal forces within a structure. What changes dramatically is the kind of thinking, the range of features, the intellectual motions if you like, the students (and faculty) must go through in order to construct a (one among many) solution.

This is one aspect of context—the context of learning. There is another kind of context—that of the exercise itself. Transforming the context of learning requires change and transformation of context *within* the exercise as well. So as not to confuse the two, I reserve context for the context of learning and simply speak of the transformation of the context within the exercise as a change in the nature, or kind of exercise.

The traditional problem is about a diving board of the sort one might find at one end of the motel pool in anytown USA. (Even this modicum of contextual description would probably be considered a waste of time in setting the exercise before the student). The board is ‘pin supported’ at the end fixed to ground while a hefty spring is positioned further out, toward the edge of the pool, to provide the necessary springiness required of a diving board. The question posed concerns the deflection of the spring when a person is positioned at the end of the board, out over the water. Here is the traditional problem statement:

A wood diving board is hinged at one end and supported 1.5 m from this end by a spring with a constant of 35 kN/m. How much will the spring deflect if a young man weighing 600 N stands at the end of the board?

Figure 1 shows a line drawing of a man standing on the board at the end over the water; the distance 1.5 m from the other end—which shows a small circle as a pin support—to the spring, and two other dimensions: the

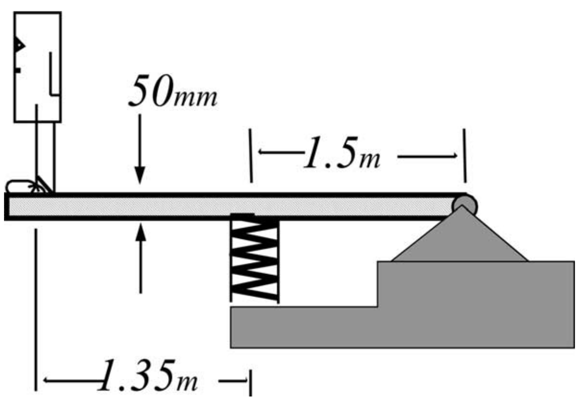

Figure 1 The diving board problem

distance between the spring and the end over water, 1.35 m, and the thickness of the board, 50 mm. This last bit of information is irrelevant to answering the question as posed, but so too is the figure of an actual person—the latter might be replaced with an arrow representing the weight of the man as a force vector acting at the end of the board. The circle indicating a frictionless pin at the support to ground is an abstraction which is provided. Observations like these illustrate the challenge of making a problem description which leads the student on their way toward a proper analysis yet which does not complexify the context to the extent that the student reacts with many irrelevant questions and fails to see how to 'get started'.

To solve the problem and prove that the spring will deflect 32.6 mm, the student must abstractly construct what is known as a 'free body diagram', a drawing of the board isolated in space, replacing the effect of the connections with the world with vector representations of the force due to the weight of the man, the force of reaction due to the displacement of the spring, and the force of reaction at the pin where the board is tied to ground. The application of the principle of moment equilibrium (about the pin) provides an equation relating the force in the spring to the weight of the man. With the force in the spring (1140 N), and knowing the stiffness of the spring—it requires 35 KN to deflect the spring one full meter—the displacement of the spring is readily obtained.

This is not meant as a report on how students do the problem. That is another kind of narrative, a narrative which can take many different forms, some of which end in confusion (Bucciarelli 1994). It is meant to illustrate the main thrust of a traditional exercise.

The transformed problem is cast as a design exercise:

Low-end Diving Board

You are responsible for the design of a complete line of diving boards within a firm that markets and sells worldwide. Sketch a rudimentary design of a generic board. List performance criteria your product must satisfy. Include on your list those features which determine the performance of the board. Focusing on the dynamic response of the system, explore how those features might be sized to give your design the right feel.

A figure is provided, in fact the same figure can be used, but now the dimensions are given as symbols, the weight of the person at the end is not specified, nor is the stiffness of the spring given as a numerical value.

The vagueness and openness of this problem statement contrasts with the exactness, albeit the clouded exactness, of the traditional problem statement. Whereas with respect to the latter, the intention is to orient, but not lead too directly, the student toward the application of the appropriate concepts and principles, here now the intention is quite the opposite—to disorient in effect; to engage the student in the formulation of an appropriate problem, appropriate questions, relevant to the context, albeit artificial, of a design task. This change in the nature of the problem dramatically changes the context within (and without) the classroom.

One of the more obvious things that changes is in what the student is expected to produce and hand in for evaluation. With the single-answer problem, a cryptic working though of the algebraic relationships, grounded in course theory, then a ‘plugging in’ of the given parameters and finally a calculation of the deflection of the spring, if done correctly, will merit a grade of ‘A’. The problem is likely to be one of several due to be completed within a week’s time. Exam questions have a similar form.

The open-ended form of the problem requires a different kind of effort and a different kind of production. I require the students to record their work in a journal; and this is to be as full a record as possible of their thinking, modeling and testing of alternative designs. They are told that I will evaluate on the basis of the way they justify assumptions and estimates; on the way they explore a range of possible configurations; on the way they test the sensitivity of their design to variation in parameters as well as on their application of the concepts and principles of the course. (It is not surprising that requiring this fuller description of their work on an exercise reveals much more about what the student has not learned). Students generally have three days to a week to ‘complete’ the exercise, at which point they hand in their journal.

The setting-out of the open-ended exercise demands a new way of relating to students as does the evaluation of their work. Because the text description is so open, time must be spent—I dedicate a recitation hour—actively discussing and setting specifications and constraints, setting out expectations of what would be an appropriate stopping point (since the exercise is open-ended, one could go on and work at it over the full semester, or more), and suggesting resources and tools they might use.

Students are encourage to ask questions of any relevance. They usually focus immediately on fixing values for parameters they know will be important: What is the weight of the user? How long can the board be?

What springs are available? I throw the questions back to the student and put them in groups of twos and threes to construct estimates.

Is the board for children as well as ‘young men’? Can we make the location of the spring adjustable by the user? Questions move off-center of the course fundamentals. What about safety; do we have to design the surface material and take that into account in estimating costs?

I may not have anticipated some of these questions but still, their treatment is the same: explore with them, through probing and questioning, what the implications for design might be in each case. Classroom discussion becomes more of a negotiation than a one-way delivery of knowledge. Students sense that the name of the game is not to figure out the answer that I have hidden somewhere in my head, but that they are now responsible as much as I for setting up the problem. Once the students sense this, the ambience of the classroom changes accordingly. Students become active participants in learning. The context of engineering education becomes more like (aligned with rather than antagonistic toward) the context of engineering practice.

5 *Conclusion*

ECSEL was not alone in attempting reform of engineering undergraduate education. There were other coalitions, other engineering schools, and many faculty who took seriously the need to do things differently if engineering education was to keep pace with, and continue to serve the needs of the profession. At the same time ABET, the accrediting agency for engineering education, was radically changing the way it would evaluate the quality of degree programs. This confluence of significant financial support from NSF and serious reflection on the criteria that should be used in judging the worth of an engineering curriculum has generated considerable activity over the past decade.

Rapid advances in the capabilities of computer and information processing technology have driven reform in many cases. Yet, to date, it has had little impact on the way engineering faculty conceive of what is fundamental to an engineering education. The technology has been put to good use in the modeling of complex systems, in enhancing faculty-student (asynchronous) communication, in demonstrating phenomena using multi-media effectively but as the ideology of engineering as applied science prevails, the disjunction remains. In fact, only if there is a turn toward more open-ended instruction will the technology’s potential be fully realized. In the design type exercise, students are encouraged to search the web for relevant information, to evaluate design options using a spread sheet, for example.

Other attempts at reform have adopted a strategy of addition—addition of more design courses, of courses in communication, ethics, teamwork and the like—perhaps extending the program out through five years. Again, the fundamental postulate holds sway—that knowledge is some kind of stuff, divisible into disciplines and skills which can be independently studied. Learning is a process of accumulating (unrelated) blocks of knowledge. This too does not address the disjunction I have defined.

A few others have proposed moving to wholly project-based or research-based learning akin, perhaps, to studio courses in architecture. But this would throw the baby out with the bath water if it became the dominate experience. Disciplined learning in the engineering sciences is necessary, essential to object world work.

There are other ways which might give due weight to preparation for work in object worlds while, at the same time and within a coherent program of study, prepare students for designing as a social process. What we have tried is but one attempt to break out of the box, the ideology which governs traditional teaching in engineering, to better prepare students for practice.

6 Discussion

(Discussant: Richard Coyne, Department of Architecture, Edinburgh University, Scotland)

RC: You reference the word 'disjunction' in the title of your paper. You seem to suggest disjunction is not a good thing, but in some quarters—certain parts of architectural studio education for example—disjunction, disorientation is regarded as quite a good thing. One of the definitions of education that I like is: 'a process that makes the strange familiar and the familiar strange'. For some philosophies of education it is the negotiation within that space, between the familiar and the strange, that learning is able to take place. Looking at what you've said in terms of strangeness and familiarity… perhaps we could see a teenagers experience of a diving board; something between terror and delight, something about the smell of chlorine and response to movement; that is a familiar experience with which a student comes to an engineering degree. And then that somehow is rendered strange, so that the diving board becomes an object of calculation, something that appears in diagrams as strange symbols, subjected to algebraic calculations with variables under notions of constraint. Then of course you suggested that learning does take place in that rendering of something strange, but then you were going another step and suggesting another level of strangeness perhaps, where the object under study becomes something to do with mass production—not the way you'd normally think of diving boards. There are issues to do with variation and negotiation and discussion, that a diving board could be the subject of a journal and so on. I was just wondering, in this trajectory of strangeness, how an architecture course might treat a diving board, not all architecture schools are the same of course, but thinking about some of my colleagues, what they might do with the problematic of the diving board—they might see it as a diving board for very very fat people, or maybe a diving board for lemmings, or maybe an object for diving into freshly picked cotton, or perhaps one can imagine a line-up of formation swimming Phillipe Starck lemon squeezers, or perhaps design researchers queuing up for their just desserts. So I only have one question and that is: why are engineers so serious?

LB: Well we have to get jobs! Clearly the context of work is very important. You are right in that we take the familiar and make it strange, the first stage being making them see that designing is not just drawing a picture, but it does involve some sort of abstract representation, in this case some of the structure and the spring, and that's done according to certain rules and certain ways of structuring behaviour in this case. That's one of the purposes of this exercise, it's not just that students learn the abstract representations of engineering science for their own sake, here the intent is to say it is useful, but it is also to say, for instance in this open-ended exercise, that it's not all that there is to the diving board, so we do cycle back to the chlorine. An exercise like this could be turned into a single answer problem, it depends what goes on at the orientation level, but the appropriate thing to do is to leave it open and let the students set the frame of the problem. Now all of this is done in a classroom context. I'm trying to replicate some kind of professional context, but the classroom context has constraints and those constraints have to be negotiated in class—so there's a setting of context, there's a context of practice, which I as a faculty member envision; there's a context of the classroom which I as an educator am responsible for. And yet I want to keep it open. It *is* open. I will allow them to use any resources they like, if they want to go to the web to check out diving boards that's fine, but they'd better tell me where they got that information from. I have them work in teams as well. That's the first thing. There were other students that complained 'they don't make diving boards like that!' other students said 'oh yes they do, I've got one in my backyard!' You have to allow for that conversation. Students will also ask about safety. They'll ask if the diving board is for big people, small people, children, do we have to concern ourselves with safety? We say something about cost, but again it's not very specific, but we have to entertain those questions seriously. You may only have time to say a few things, but at least you don't shut it off and laugh at it, or ignore it. It's a legitimate concern, and you can simply say if it's a concern with safety or ethics perhaps, or say the United States is a very different society to Europe, we could get a discussion about international relations there, and that might be appropriate. Regarding the more surreal aspects of imagining a solution, I try not to over-constrain it in that respect. I mean if you were my student I'd allow your exploration, but it has to spring from the student. If the student comes back and says, but we can also use this for lemmings, I'll say 'fine, as long as you can justify that.

Questioner 1: I've done similar projects with design students, but there are problems. I think that the majority of design students when they've worked on open projects with me is that they tend to answer the openness rather than the project, and they notoriously exceeded the brief and didn't meet it. For example they'd end up giving me a video about diving boards that took a million hours to make, and is full of philosophies about outer space.

LB: The students will get carried away with technique, they'll give 18 significant figures in their spreadsheets, I try to control that. They have certain tools available to them—they have spreadsheets of course—and they will get carried away, but again they have to decide. How many alternatives do they consider? I try to say something about what is expected so that I can evaluate it, but I still don't want to close them off. If they do get really engaged in doing some things I can say 'well that's excessive in my evaluation. Talking about evaluation though, I've always had a problem with the evaluation of this kind of teaching? How do we evaluate the effectiveness of this sort of teaching with respect to the more traditional kind, certainly it costs more at this stage of doing this, I mean if we're preparing for a lecture it takes half an hour and then we have teaching assistants to grade the exercises so what could be more productive than that right? But this takes more, actually there are many teaching assistants who would be able to do this.