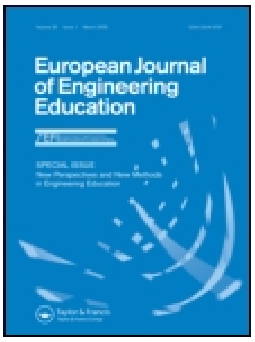

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Ethics and engineering education

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In the US, Accreditation Board for Engineering and Technology (ABET) recommends the study of ethics so that students acquire 'an understanding of professional and ethical responsibility'. For the most part, teaching of the subject relies upon the use of scenarios – both hypothetical and 'real'– and open discussion framed by the codes. These scenarios and this framing are seriously deficient – lacking in their attention to the complexities of context, almost solely focused on individual agency, while reflecting too narrow and simplistic a view of the responsibilities of the practicing engineer. A critique of several exemplary scenarios, and consideration of the demands placed upon today's professional, prompt reflection on the need for, not just a more expansive reading of the codes of ethics re what it might mean to be 'responsible', but a substantial reform of undergraduate engineering education across the board.

Keywords: ethics; social responsibility; engineering education

1. Introduction

In the US, the Accreditation Board for Engineering and Technology (ABET), recommends the study of ethics so that students attain 'an understanding of professional and ethical responsibility.' I must confess that I have never felt comfortable with this directive and with the way the subject is generally taught. The exercises students are assigned and engage strike me as artificial. They neglect the social nature of day-to-day engineering. In focusing solely on an *individual* agent's possible courses of action they oversimplify; they are not a valid abstraction.

Ethics ought not be neglected in engineering education, but more fundamental and prerequisite is for students to learn about the social, the organisational – even the political – complexities of practice. To accomplish this, a major renovation of engineering education is required – one that goes beyond adding an ethics course to the curriculum. What's needed is to open up the engineering classroom to perspectives other than those which see every task and challenge an engineer faces as a problem to be solved – by an individual, alone.

To ground my critique, I consider two examples. The first exercise is a hypothetical case, used by Professor Peter Meckl of Purdue University in a controls course. The second concerns the decision to launch the challenger.

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2. Two cases

Professor Meckl's example is introduced alongside the technical material of an upper-level control systems course. Here is the exercise: (Meckl 2007).

Airbus Autopilot Case

> You have been working for Airbus as a control systems engineer for about 1 year. After spending time mainly coming up to speed, you have just been asked to solve some problems on the autopilot software for commercial Airbus jets.
>
> The software has been designed to perform many functions previously performed by the human pilot. Besides speed and heading control, it also tries to assess current conditions and makes decisions to improve current performance.
>
> Early reports from airline pilots suggest that under certain conditions, the autopilot performs control actions that actually can cause the plane to stall and potentially crash. Only quick thinking by the pilots has saved the aircraft in the past.
>
> You have been asked to figure out what's going wrong. However, in the meantime, planes are still flying with the installed software, posing the risk that a fatal crash is only matter of time.
>
> What should you do?

The second example concerns The Space Shuttle Challenger Disaster. The standard way this case is presented (Texas A&M 2007) starts with a detailed description of the failure of the O-rings meant to contain the hot gases during the firing of the solid rocket booster (SRBs); then comes a report of the teleconference, held the evening before the day of the launch, among engineers and management who were faced with making the decision to launch or not to launch the next morning. The story reaches its climax when NASA's SRB Project Manager, turns to Thiokol's Engineering Vice President, and says,

> Take off your engineering hat and put on your management hat.

The decision is made to go ahead with the launch. One is tempted to conclude – if only the engineers had been more forceful, (stomped out of the room?) right scientific reasoning would have prevailed in the face of managerial pressures.

3. On the nature of engineering practice

Understanding my unease, requires an explanation of how I see engineering practice (Bucciarelli 1994): Generally engineers work in teams, in groups large and small. Different participants bring different expertise to a task. Each has his or her own disciplinary perspective; their own ways of abstracting and modelling. Each can rely upon an infrastructure with its own special instruments and tools, prototypical bits of hardware, reference texts, suppliers' catalogues, codes, and regulations. I say that different participants work within different *object worlds.* Each participant, with different competencies, responsibilities, and interests sees the object of design differently. The *one object* of design presents *multiple object worlds* to different participants.

As a result, participants' analyses, proposals and claims will conflict. Each participant has to articulate his or her claims, analyses, and proposals so that others, those who inhabit other worlds, can establish meaning both with respect to their own perspective and the project as a whole. Within object worlds, instrumental rationality may carry the day; but within this now more open world of exchange and negotiation, validity claims are not restricted to objective statements that describe the structure and function of the object from one or another specialist's perspective. Here, now, the field of play is open to the traditions and norms of a firm which guide (and constrain) question-posing and decision-making – open to business and managerial analyses and claims, open even to prevailing popular ideologies and political interests.

And engineers are essential participants in this kind of work. *Object-world work is indeed necessary to design but it is not sufficient.* What engineers do, and are expected to do, includes much more than rational problem solving and constructing efficient means to reach desired, externally specified ends. In engineering practice, value judgements are made all the time, often not explicitly – about the user, about robustness, about quality, about responsibilities, safety, societal benefit, risks and cost. However, it is object-world work that is seen as primary by engineering faculty – and consequently seen as such by our students. It is what we teach in our core curricula – the 'hard' stuff – whereas the social is generally not seen, neglected, or made a laughing matter.

Consider this picture of engineering culture: (Herkert 2001)

> The prevailing engineering culture is readily recognised from both inside and out. Engineers are no-nonsense problem solvers, guided by scientific rationality and an eye for invention. Efficiency and practicality are the buzzwords. Emotional bias and ungrounded action are anathemas. Give them a problem to solve, specify the boundary conditions, and let them go at it free of external influence (and responsibility). If problems should arise beyond the work bench or factory floor, these are better left to management or (heaven forbid) to politicians.

4. Critical analysis of the cases

It is the lack of any substantive treatment, none the less recognition, of the social context of the situations with which we confront our students in these scenarios that is the source of my unease. The focus on the *individual* agent, hanging there, alone, confronting some identifiable ethical question strikes me as too simple a representation of what an engineer faces in practice.

It is an abstraction that may work well if the intent is to teach moral philosophy – part of a moral philosophy object-world so to speak. The cases can then be read as 'set-ups' for an exposition of philosophical concepts and principles. This may provide an effective way to introduce students to different bases for ethical choice – individual rights, utilitarianism, deontology, Kantian imperatives – perhaps useful too in showing students how to reduce an ethical problem down into its factual, conceptual and moral dimensions – but the abstraction is seriously deficient in attending to the context of engineering work.

Consider the Autopilot Case: The ethical situation strikes me as unreal because it pictures the neophyte controls engineer so distant from any other participant who might have a legitimate interest in the problem. I recast it now in the light of my view of engineering practice:

Airbus Autopilot Case

> A year out of university, John joined a team at Airbus as a control system's engineer The team –consisting of a seasoned pilot, a senior software engineer, and another, more experienced, control's engineer–had designed, developed, and tested an upgrade to the autopilot software for Airbus' commercial craft.
>
> The team had been asked to solve some problems in the software. The software had been designed…
>
> Early reports (but not in flight test?) from airline pilots suggest that under certain conditions, the autopilot performs control actions that actually can cause the plane to stall and potentially crash…
>
> The team has been asked to trouble shoot the design, determine the cause(s) of the problem, and recommend a fix to the software –while the planes are still flying.
> What should John do?

The technical facts are the same, but what has happened to the ethic's problem? It hasn't exactly disappeared but certainly it has taken on a different thrust. Making the individual, John, part of a team alters the story in a significant way; the responsibility for remedial action is no longer yours – rather John's – alone but the team's, the group's.

Is this an ethical problem at all? Would John, on the job, think of it as such? Would the student – say he walked in late to Professor Meckl's controls class – see it as an ethics problem? I conjecture he would not; he is more likely to see it as a design challenge and try to construct a technical 'fix'.

This suggest that if an ethics scenario is to be a more valid abstraction of what an engineer might encounter in practice, distinguishing the ethical problem from the technical problem may not be easy and will require constructive effort on the part of teacher and students. Such would encourage the students to question and probe the problem as stated – (Why is John singled out for action?) – and should lead to conjecture and analysis of the social complexities of engineering practice, i.e. that there is something more to doing engineering and dealing with ethical issues than finding answers to well posed problems within a moral philosophy object world – but, again, that is precisely what is needed in order to teach 'ethics' (and engineering!) with integrity.

This is particularly true if one is to do justice to the Challenger case. Here, fortunately, we have the scholarly work done for us. Diane Vaughan, in her 'revisionist history and sociological explanation' *The Challenger Launch Decision* (Vaughan 1996), challenges the conventional interpretations – those that claim that '…the launch decision rested on a rational choice theory of decision making: amorally calculating managers, experiencing production pressures, weighting costs and benefits, violating safety rules, then launching' (Vaughan, p. 403). Her analysis reveals, not a case of unethical behaviour, but the 'sociology of a mistake'.

But what about

> '[It's time to] take off your engineering hat and put on your management hat'?

To read this as meaning that management over-ruled the solid analyses and data of engineers is wrong according to Vaughan. The engineering data was not conclusive (is it ever?). Those participants with engineering responsibilities strongly opposed the launch but

> …apparently they did not believe the SRB joint would fail. They believed that they were entering into an area of increased risk, that more damage to the O-rings might occur, but…no one thought that a complete ring burn-through was possible. (Vaughan, p. 380)

This is not to deny that the pressure to launch was a factor, but to find in this the sole motivation for decision-making is wrong and misguiding. Individuals act with mixed motivations. Nor is it to deny responsibility on the part of participants, attributing the failure to the conjunction of certain social forces and/or cultural patterns alone. But it is the responsibility of individuals as part of a collective, a shared responsibility that is the issue here. (Here I differ with Michael Davis who states 'The trouble with Vaughan's approach . . . is that it effectively frees the decision-makers at Morton–Thiokol of responsibility for the decision they made the night before the launch.' (Davis 2006, p. 225).)

What becomes of the ethics problem after reading Vaughan's book? Again, it seems to melt away or at least become something more complex. To move beyond myth-making about whistle-blowing and to prepare students for recognising the antecedents of, and sociology of mistakes, one can start with Vaughan's summary analysis found in her final chapter. There she talks about 'paradigm' and 'structural' (not engineering structure, but sociological), and 'script' and 'social construction' and 'culture' and how to do good history (ethically), and calls upon the insights of authors like Kuhn, Latour, Geertz – so they need to be read if one is to grasp the full force of her analysis.

And what do we learn from Vaughan's analysis? First, organisational culture matters; it sets the context for beliefs about what is important, what can be ignored; who is important, who not so; it guides and constrains modes and channels of communication – informal as well as formal.

But beyond this we learn that instrumental, rational analysis never suffices in practice. Decision making in engineering is a multi-factored affair and not all factors can be quantified. In this case, object-world analyses and field and laboratory test data did not suffice; the engineering narrative did not convince. What appeared to Biosjoly as hard evidence for failure, appeared to others as ambiguous, tentative, unconvincing.

We see too that in the design, operation, and maintenance of complex engineering systems, responsibility is shared among participants in a project. Seeking a root cause and/or fingering a single individual to blame (or praise) for failure (or success) might make a good story but it is likely to be a superficial rendering of events and, as such, does a disservice to the intelligence of our students.

This is why the Challenger disaster is an interesting case to study – for the questions it raises about engineering practice; about the norms embedded in organisational culture; about the limits of rational instrumental thinking; about engineering as a social process. (Didier (Didier 2000, p. 329) similarly reports how so much more can be gained from, not 'case study' which '. . . often presupposes a particular approach and a search for a "right solution". . .' but from 'Stories, real-life stories').

The deficiencies in these cases representation of the social complexities of engineering practice is one reason for my unease. A related source of my unease is the image of the engineer that is implied by the codes of ethics.

5. The Ethical Engineer–according to code

We have already encountered the engineer as rational, no nonsense, object-world, problem solver. A study of the 'Fundamental Canons' (ASME 2006) and the criteria for their interpretation shows the ethical engineer further deformed; a modest individual, fully competent but so only within a narrowly defined domain; one who should not question a colleague's work – unless, of course that person breaks the rules of ethical conduct, at which point one is required to blow the whistle. First and foremost, the ethical engineer is a loyal member of the firm. Even the 'public welfare' canon does little to brighten the image; 'safety, health and welfare of the public' is read as a demand for product safety alone – as a means to avoid liability For a critical review of a deontological-based teaching of engineering ethics see (Didier 2002) not as a call to social responsibility. (For a critical review of a deontological-based teaching of engineering ethics see (Didier 2002))

This image of the engineer is one that resonates with the popular image of the hard working student – intensely struggling to grasp the concepts and principles of thermodynamics, computer science, mechanics, differential equations etc. and apply them in the solution of well-defined, given, problems that admit of but a single right answer – an individual loyal to, and unquestioning of, the business of engineering science. The connection is made explicit in the following quote from a summary of observations made by an MIT Corporate Advisory Panel in the not too distant past: (MIT 1992).

> MIT Graduate: Not as perfect for industry as before. Typical product of MIT education – an excellent individual performer but often considers it *just about unethical* to use results of other people's work. This attitude must change. (emphasis mine).

I have puzzled over this observation since the summary report crossed my desk more than a decade ago. Why would a student consider it *unethical* to use the results of the work of others? I think it is the graduate's (product's?) distrust of the work of others, a felt need to do all the work on one's own, that is at issue here.

Unfortunately, some seem to expect little more from the engineer. Consider how Norman Bowie defines the good engineer (Bowie 2005)

> What is a good engineer? A good engineer is one who lives up to the obligations of her employment contract, who conforms to the etiquette of the job situation she finds herself in, and whose *individual* (emphasis mine) engineering practice at least equals the performance standards of the profession.

Obligations of an employment contract? Etiquette of the job? (What does that mean?) Practice which minimally meets standards of practice? Is that all that we can expect of our engineering talent? If this is a 'good engineer' how will we ever attract any into the profession? What room for creativity? The esprit of a team effort? Where is the good life, the virtuous effort?

I think of our students' positive inclinations to 'do good', to better the environment, conserve energy, bring appropriate technology to developing countries, bio-engineering for the improved health and welfare. I think too of the projects students engage outside the curriculum – projects intended to be socially beneficial. (Michael S. Pritchard, (Pritchard 1998), critiques the 'minimalist view' (stay out of trouble) and offers brief descriptions of several cases of exemplary practice engaged by students.)

Consider *The Graduation Pledge of Social and Environmental Responsibility* initiated by students at Humboldt State University in 1987. (Dalhouse University, School of Management, Nova Scotia is one of the seventy.http://www.humboldt.edu/∼career/gpa/history.html [online Oct. 2007].) It reads

> I pledge to explore and take into account the social and environmental consequences of any job I consider and will try to improve these aspects of any organisation for which I work.

A code of ethics that interprets public welfare narrowly, as ensuring product safety (so as to avoid legal suit) will no longer suffice. What needs attention is the social responsibility of the profession as a whole.

This concern with the need for a more collective response to today's problems on the part of the profession is not new. In 1979 John Ladd wrote: (Ladd 1989)

> Perhaps the most mischievous side-effect of codes of ethics is that they tend to divert attention from the macro-ethical problems of a profession to its micro-ethical problems. There is a lot of talk about whistle-blowing. What is really needed is a thorough scrutiny of professions as collective bodies, of their role in society and their effect on the public interest…

Let's leave the codes aside then. What becomes of engineering ethics? Can we dare speak of moral responsibility – even of virtue – of the profession? By this I do not mean to imply that a professional engineering society as a corporate entity ('ideal type') in itself possesses virtues, rather I mean that participants in the professional culture – share certain values and beliefs and abide by (mostly unwritten) norms about what contributes to, or denigrates, the public welfare, that these shared values define the integrity of the profession, and guide engineers in their day-to-day efforts. (Conlon's (Conlon 2008, this volume) argument for a broader focus in the teaching of ethics '. . . on the social structure and the way it both enables and constrains social responsibility' is relevant in this regard. See also (Pritchard 2001).)

Deborah Johnson in 'The Social/Professional Responsibility of Engineers' (Johnson 1989) distinguishes between (individual) personal and (collective) professional values and judgements. She argues that any recognition of professional values, points to the commitment of all engineers to a shared value and such commitment

> …should not be underestimated. It defines the framework within which members of the profession must make their decisions.

She contrasts two conceptions '. . . of professions in the world, and two different conceptions of engineering.'

> One conception is to view professions as being value neutral, with the values directing them coming from outside. On this model it follows that engineers can and should be guns for hire . . ..
>
> The other conception is to view professions as enterprises committed to a social good and being structured (constrained in various ways, privileged in others) so as to achieve that social good. . . . In this conception of a profession, and only in this conception, can we understand engineering as a morally worthy enterprise, worthy, that is, of individual commitment and social recognition.

If you accept the vision of engineering practice promoted and sustained by the object– world notion then it follows that the profession is ‘value neutral’, that we are all but ‘guns for hire’. This vision is implicit in all of our teaching in the core of our disciplines. But it is a myopic vision: The profession of engineering is not value neutral. But what to do?

6. Engineering education – beyond ethics

There are several options we, as engineering faculty, might consider:

1. Forget ethics altogether as our responsibility; we are not qualified to teach the subject; our responsibility is to teach object-world, value-free engineering.
2. Introduce ethics ‘problems’ into an engineering course, taught in collaboration with people who do have the competence to teach the subject. I call this the ‘separate but equal’ approach. (Some programs have made significant attempts to infuse ethics ‘across-the-curriculum’ such that ‘. . . ethics and safety are seen as common attributes of good engineering practice.’ (Steneck 1999). Herkert, in his critical appraisal of the teaching of engineering ethics (Herkert 2000), notes how, in practice ‘. . . because the material is often covered in small chunks in disparate courses’, depth and continuity in the study of ethics and the level of integration achieved is far from the ideal.)
3. Reform the whole of the engineering programme to enable student (and faculty) understanding of the social as well as instrumental challenges of contemporary professional practice and what this might mean for the profession’s ‘social responsibility’ (and ethical behaviour of the practicing engineer).

It’s the third option that I favour and see as necessary. But I would go beyond the addition of a course in science, technology, and society (STS). (Kline 2001) The current value system underlying our teaching of the ‘hard’ subjects, even the prevailing approach to teaching most design courses has to change.

The way we structure our curriculum and teach our subjects all conspire to instil in the student the idea that engineering work is value-free. Object-world work may be, but that is but one part of engineering competence. While teaching the ‘fundamentals’ of science and mathematics, and the engineering sciences remains necessary, we must do so in more authentic contexts, showing how social and political interests contribute in important ways to the forms of technologies we produce. We ought not as faculty imply as we do, that solving single answer problems or finding optimum designs alone, uncontaminated by the legitimate interests of others is what engineers do all of the time. This is irresponsible.

We need to open up the engineering classroom to discussion and debate. What is needed is a schooling of engineers rooted in a more ‘liberal’ tradition, engaging engineering knowledge and know-how, still with science and technology at the core but in a setting that allows students to challenge the ‘givens’, even the suitability of ends. Students should be encouraged to critically reflect upon the methods for modelling and problem solving, design and building as well as experience (and learn) the power of these techniques. This will require a new faculty, a mixed faculty, not individually generally knowledgeable about all dimensions, but as in engineering practice itself, each able to articulate their interests to others and to listen with full respect. And it will, I suspect, require a move toward project based learning.

A three–two programme suggests itself. Three years of more general, open study, then two years of more focused study, at a masters level. (I am not advocating the kind of liberal program promoted by Samuel Florman (Florman 1968). Think, rather, in terms of a 3–2 structure akin to the BA–MA programme arrangement that has been introduced within the European Union through the Bologna process.)The first phase (at least) would be the responsibility of a mixed faculty of philosophers, historians, sociologists, even classicists, as well as scientists, mathematicians and engineers with authority and control over content and context shared. (To ensure this would not degenerate into a collection of independently taught humanities subjects and engineering science courses, accreditation would be by a mixed review board. ABET's changes in accreditation criteria *originally* (2000) promised to allow for significant flexibility in the design of structure and content of engineering programs. How ABET would respond now to such a proposal is unknown.)The engineering sciences would be part of this but not dominate; critical appraisal of origins and impacts, reflection on values implicit in the doing of engineering would hold centre stage. But this is not the place, nor is there space, to argue this further.

7. Conclusion

I have argued that the way ABET's recommendation for the study of ethics has been implemented within engineering programs falls far short of the mark – if the intent is to prepare graduates for reflective, socially responsible professional practice. I have conjectured that an authentic encounter with ethical questions will require a more expansive and critical study of engineering, including its social/political dimensions – in effect displacing ethics as a subject in its own right, moving it aside in order to get at more fundamental features of practice.

This is not the place to explore what might be taken as appropriate content in a program of the sort proposed above, what effective ways of engaging students might be employed, nor what it would take to convince engineering faculty that such a significant change is needed to prepare our students for responsible, professional practice in this day and age. Indeed, the author agrees with one of his reviewers that '. . . few, if any, Schools of Engineering would accept to follow such radical suggestions'. Admittedly, this is a lot to ask of engineering faculty. Yet, if we, as engineering faculty, still claim that it is our job and responsibility to teach 'the fundamentals', it's time explicitly to recognise that what is fundamental to engineering practice goes beyond scientific, instrumental rationality; I hold that failure to acknowledge this fact is 'just about unethical'.

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Louis L. Bucciarelli (PhD, Aerospace Engineering, MIT), is a Professor of Engineering & Technology Studies at MIT, now emeritus. He has held a joint appointment in MIT's Program in Science, Technology and Society and in the School of Engineering. Early on his research focused on problems in Engineering Mechanics – static and dynamic structural stability – and in the History of Science, authoring a book with Nancy Dworsky and Sophie Germain: *An Essay in the History of the Theory of Elasticity* (Reidel 1980). Over the past two decades, he has studied engineering practice from an ethnographic perspective (Designing Engineers, MIT Press 1994); ventured to explore how philosophy might matter to engineers (Engineering Philosophy, Delft University Press 2003); and is currently drafting a book on Engineering Education with Arne Jacobsen of the Danish Technical University. Throughout his career he has been involved in attempts at curriculum reform, e.g. serving in the 90s as a principle investigator with the NSF funded ECSEL coalition for the renovation of undergraduate engineering education. He is the creator of the 'Delta Design' design negotiation game – an educational exercise used throughout the world to introduce students to the complexities of engineering design viewed as a social as well as instrumental process.