Appendix 5. Engineering Practice Concepts and Misconceptions

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This appendix to the book "The Making of an Expert Engineer" provides a table of misconceptions and practice concepts, summarising they way that students (also graduates, many novices) perceive the issue, education factors that contribute to these perceptions, the impact and consequences on practice, the learning barriers that result from this, and some suggestions for education interventions that could help students come to a more helpful understanding of the relevant concepts. Education interventions have not yet been provided for every practice concept. Further suggestions are welcome.

Number	Page Refs	Category	Title	Type	Engineering practice: observation	Perceptions by students	Education factors	Practice impact, consequence observed	Impact on learning, barriers	Intervention strategies
MC01	Pref:xxviii	Practice	Socio-technical factors are non-technical issues	Unstated	There are few if any factors that shape the contours of practice that have no technical implications or dependencies. Two of the main attributes that distinguish expert engineers are their abilities to perceive how technical factors and social interactions shape the landscape of practice and to influence people working with them to preserve the technical intent through multiple reinterpretations by other people.	These are all non-technical issues	Students are only introduced to technical factors shaping the lanscape: therefore, other factors are labelled as "non-technical".	Reluctance to engage in non-technical courses such as communication, working with clients	Blocks effective learning of people skills, also socio-technical skills.	Understanding more about structure of collaboration and its importance might help engineers pick up skills and confidence to learn more.
MC02	3:44-6	Practice	Engineering is a hands-on occupation	Assumption, unstated	Most engineers rarely (if ever) perform hands-on work, and are often required to ensure that any hands-on work is performed by technicians with appropriate qualifications. For an engineer, hobbies provide the main opportunity to perform hands on work. If this is important for you, start a hands-on hobby now.	Engineering is a hands-on practical occupation, it's important to be able to work with your hands on real equipment.	Expectations (Dilbert, the Knack), popular misconceptions, locomotive drivers and aircraft "engineers", lack of hands on in practice not stated. Hands-on skills are implicitly valued, often explicitly (e.g. hands-on experience in labs), but not when it comes to marks. Lack of assessment means these skills are also, at the same time, devalued implicitly. Lab marks do not depend on your hand-on ability, only ability to write a report. Introduces a contradictionand discomfort?	Some experience frustration at limited opportunities for hands-on work, others have limited opportunities to improve their practical understanding, making it more difficult to appreciate knowledge of technicians. The use of the term "hands-on" sometimes means that engineers can see practical things happening, even though they don't actually touch or do anything with their own hands.	Inability to understand or value tacit, unwritten, hands-on know-how means it its significance is missed in understanding organisational capacity.	Restore people to central place in practice, learn about different kinds of knowledge and how they are used. Explanation, repetition.
MC03	3:46-7	Collaboration	Engineers are naturally logical	Repeated often	Engineers are often neither concise nor logical. Engineers exhibit all the different characteristics of other people.	Engineers express themselves concisely and logically (in comparison to others)	Myth	Communication difficulties are not recognised early enough, dismay and frustration in presenting cases for improvement only to have them rejected, arrogance towards view of non-engineers, especially clients.	The idea that engineers are logical (more so than others) is deeply embedded and a difficult obstacle to overcome.	Requires case studies and examples of simple argumentation to help expose weakness in this area, and then help overcome this weakness. Progress may be slow at first.
MC04	3:47-8	Knowledge	Engineers work with objective facts stated in numbers	Unstated	Reasoning with numbers and mathematical equations is only as good as the assumptions behind the data. Measurements often depend on the skill of the operators using or installing instrumentation. Numbers taken out of context can be quite misleading.	Engineers prefer objective facts: numbers can convey more precise and objective facts than words. Facts explained with words tend to be fuzzy and subjective.	Students think that words are "subjective" and numbers are "facts". An argument is said to be biassed if it is based only only on words without facts.	Engineers miss the idea that an argument can be biased through selective inclusion of facts, and also that numbers may represent a filtered reality, already "biased" by the method used to obtain the data.	Engineers tend to resist learning how to use words effectively, believing that it is only numbers that count.	Simple case studies like one cited in the text will help.
MC05	3:48-9	Problem-solving	Engineers are problem solvers	Contradiction	Solitary design and problem solving is usually less than than 10% of time, analysis & modelling is also less than 10% of the time (except for a few engineers). Expert engineers know how to avoid problems in preference to solving them. Problems without well-known, tried and tested solutions add to uncertainty.	Solitary work on technical problem solving and design form the main components of engineering practice. Other aspects are either irrelevant or of lesser importance.	"Engineers solve problems" is a phrase that is repeated endlessly throughout education, and demonstrated through practice exercises in which students mostly solve essentially closed form problems.	Frustration, uncertainty (do you think the work is more technical here or somewhere else?), searching for other opportunities, frustration at not having much opportunity to use "skills for which I have been taught." Frustration and feeling of incompetence when confronted with challenges that require other styles of thinking and action.	Perception that other aspects of practice are secondary (from design and problem solving) inhibits willingless to learn other skills.	Research evidence can help demonstrate reality, validating subjective individual observations. Increase focus on practicing delivery processes: planning, monitoring, risk management, safety.
MC06	5:98-9	Knowledge	We need to know it all	Unstated	Good engineering works because knowledge is distributed in the minds of different people: it is not necessary to know everything, but you do need to know how to find someone you can ask and how to get them to help you. Above all, when you don't know, say so.	Technical expertise (solo) is what distinguishes an engineer. Have to know your technical "stuff" otherwise you will lose respect of peers and boss. Asking for help is a sign of giving up, a kind of cheating, a last resort. If you don't know it, look it up in texts, on-line, library, wikipedia (if you can get away with it), and never admit that you don't know.	All marks (nearly all) gained for individual knowing, explicit written knowledge.	Novices (mainly) often waste time by trying to find information for themselves (internet, reading), and don't think to ask for help (isn't that, kind of, cheating?). Females may be more predisposed to lack of self-confidence from not knowing the right stuff. Younger males like to show off to hide their own lack of self-confidence.	Implied value of knowing it yourself inhibits learning of skills needed to ask for help.	Explain the impossibility of knowing it all, structure of engineering knowledge. Once the complexity evident in figures 5.10 and 5.11 (pp135-6) is evident, it might be easier for engineers to understand this and work with the practice exercise 2, p146.
MC07	5:116	Knowledge	Self-learning is needed because technology keeps changing	Commonly stated	job all the time. Most of what engineers need to know is learned on the job, preferably from more experienced people such as engineers and site supervisors, occasionally in formal courses. Expert engineers are learning every day of their career, and even beyond retirement. That's why they have become experts.	Lifelong self-learning is needed to keep up with technology changes. You need to be good at reading books for that stuff.	Myth, commonly propagated by academics, in some handbooks.	In some environments, engineers think that all they need to know is what they were taught, or is in books. Most soon learn that this is not the case.	Mostly engineers do the learning, without necessarily realising it. For example, they will say "I'm getting up to speed on this project", in reality, spending time learning what it's all about.	Reflective discussion comparing workplace learning (e.g. reading documents) with other forms of learning might be helpful.

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MC08	5:116-8	Employment	Grades matter	Unstated	Workplace performance is unrelated to course grades because practice requires so many other skills and abilities that are not learned at university. Ability to learn these other capabilities determines success, for example, building collaborative relationships with more experienced engineers, suppliers and site supervisors. Also course grades depend on many factors other than academic ability and motivation.	Getting good grades at university makes you a better engineer. A high average grade demonstrates a better work ethic.	Throughout education experience, students are rewarded for top grades with prizes and other incentives.	Students focus effort on activities that reward them with higher grades (assessment-driven behaviour), and continue similar activities in the workplace as novices, focusing on individual achievement rather than helping others.	Non-graded aspects of education (e.g. teamwork, interpersonal skills) are not considered worth knowing. This may also make it harder for novices to be aware of learning tacit and unwritten knowledge.	reflecting on understandings of practice could help novices understand why this happens. The breadth of skills needed for collaboration which takes 60-80% of their time exceeds any learned in higher education by a wide margin. We have developed instruments to measure tacit knowledge acquisition that could be used as models for demonstrations about learning unwritten knowledge.
MC09	5:144-6	Knowledge	It's all psychology and management, not engineering	Commonly stated	Engineering practice relies on people: engineers only create value through the hands of other people.	Interaction between people is nothing to do with engineering: that's psychology or management. If it's not a technical problem, it's a management issue, not an engineering issue.	Myth	Engineers demonstrate difficulties dealing with people, in multiple dimensions, and tend to reject efforts to help them improve their skills because they don't identify this as part of engineering.	Invisibility of people (even the self) prevents effective learning of relevant skills.	Perhaps start with the notion that engineers rely on other people to provide finance and implement their ideas. Hence collaboration quality determines the quality of the result, and that involves people issues. Appeal to engineers' logic?
MC10	7:191-2	Collaboration	I'll need communication skills when I'm a manager	Commonly stated	Engineers need to collaborate with others, and this requires communication.	Engineers work in technical roles for the first few years and don't need people skills. Later, if an engineer goes into management, that's when he or she will need people skills.	Myth	Reluctance to learn, practice communication skills.	Reluctance to learn people skills self-reinforces.	Exposing data in figures 3.1-3.6, pages 51-53 might be a good place to start. Given the large proportion of time spent on communication, even small improvements could provide worthwhile benefits.
MC11	7:193	Collaboration	I already have good communication skills	Commonly stated	Employers complain about the poor quality of novice engineers' communication skills	Marks awarded for written assignments, particularly project reports, and marks for technical presentations reflect communication skills performance.	Communication skills teaching and assessment is based on written reports and occasional verbal presentations.	Employer frustration, focus on communication skills needed in graduate development programmes, causing resentment among novice and mid-level engineers. Firms' desire to give grads leadership skills training reflects perceived gaps in their communication skills.	Perception by students that they can communicate well translates into resistance in learning situations, disappointment with grad programmes for emphasis on "soft skills"	Perhaps get engineers to reflect on the things that frustrate them. Almost certainly this will expose weaknesses in communication skills, and this might provide the opening needed. Self-efficacy will be needed, so start with small, achievable improvements.
MC12	7:193-4	Collaboration	Communication and teamwork skills cannot be taught	Commonly stated	Novice engineers do not seem to know about collaborative work practices, nor do they seem to practice them.	Teamwork and communication skills are learned by practice: they cannot be taught.	Communication skills teaching and assessment is only based on written reports and occasional verbal presentations: teamwork skills are rarely taught or assessed.	A robust misconception that lasts decades. Employer frustration, focus on communication skills needed in graduate development programmes, leading to resentment among engineers as they don't identify this as "real engineering". Firms' desire to give grads leadership skills training reflects perceived gaps in their communication skills. Compounded by delivery of courses in a non-technical context by people who don't see that technical communication is something special.	Perception by students that they can communicate well translates into resistance in learning situations, disappointment with grad programmes for emphasis on "soft skills"	Data from Robinson (2013) shows that engineers who have had some formal training in communication skills find they are better at it and more confident, even though they still tend to agree with this myth.
MC13	7:194-5	Knowledge	My boss will tell me what to do	Unstated	Engineers are expected to know what to do.	Your boss will tell you what to do.	Not mentioned	Young engineers stop and wait for direction when they get stuck, reluctant to take initiative.	Among young engineers who tend not to take initiative, this might be a difficult obstacle.	Some of the case studies might help here. Get engineers to contribute their own examples. Possibly they need confidence and courage to try. It is worth remembering that people with courage still feel fear: however, they take care to protect themselves, and do it despite feelings of apprehension. By getting novices to expose their emotions (safety needed), they might be able to address this issue easier.
MC14	7:195-6	Collaboration	In the real world, slackers will be fired	Unstated	Teams often dysfunctional, freeloaders (I.08)	Teams work well in real world because freeloaders will be fired: everyone contributes equally in the real world.	Team skills are not taught explicitly: only the implicit message that as marks are distributed equally (often but not always), team work requires equal contributions by all.	Teams don't work well (often) in practice, causing stress, tension, conflict. Little evidence of novice engineers even knowing how to collaborate and being able to exploit team work for their advantage (e.g. use in checking).	Weakness in verbal skills (which gets worse with increasing education in engineering, at least in terms of perceived importance by students), inhibits learning of teamwork skills.	First level is to understand that team contributions are always unequal, and what counts is the potential contribution, no matter how small. Understanding concept of distributed expertise, developing social skills, value frameworks (Ch8, pp268-72 and Ch12, pp 439-46) building trust, restoring people to centre of practice, understanding construction of mental models. Once understood, perceptions can be explored and possibly changed. At least the constraints will be clearer.
MC15	8:251-2	Collaboration	A concise and logical explanation is sufficient to convey a technical idea	Unstated	Many engineers think that this is sufficient, without realising that much more is usually required. Engineers complain about the inability of other people to understand, even "project" engineers, and often only feel comfortable talking with like-minded specialists.	That is sufficient to convey a concept to another person. For non-engineers you need to talk in non-technical language.		Widely held misapprehension, leading to great frustration (e.g. I sent them the information they needed, why did they not read it?).	The main barrier is the model established by years of university engineering teaching that follows this model.	One possible avenue is to explore the weakness of university teaching: it didn't work. Engineers cannot apply their learning in the workplace (normally) and so something different is needed, even for small workplace learning challenges.

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MC16	14:511-2	Employment	Engineering jobs are advertised	Unstated	Many if not majority of jobs obtained through informal networking. Employers hope that they will meet experienced applicants but know that they will have to train them otherwise.	Companies advertise for engineers when they need them. Most jobs require experience.	Reinforced by behaviour and by recruiting practices of major companies (who do advertise and have formal processes, very time-consuming for students). Also reinforced by career presentations by companies.	Graduates waste time responding to advertisements, applying for hundreds of jobs in some cases. Graduates are unaware of the informal job market where most jobs are found.	No understanding of need for networking. However, knowing that 80-90% of jobs are not advertised may be enough to overcome this barrier, at least to begin looking for something else. Shyness in approaching others is likely to be a barrier to overcome.	Explanations: high motivation to seek work once financial pressures come into play. Receptive to advice, but it often has to be through person-person contact. Engineers are not natural readers, nor may be comfotable with face to face contact with people who may tell them to go away.
MC17	14:511-2	Employment	You cannot get most engineering jobs without experience	Unstated	When a company has a job vacancy caused by the resignation of an engineer, they will advertise the job hoping to receive applications from engineers who have at least the same experience as the person who has just left. Naturally the company would prefer to hire somebody with the same kind of experience or even better. However, if no one with appropriate experience applies, the company may have to employ the best available.	Usually students are unaware of this		Graduates don't pursue obvious opportunities to gain jobs and experience.	Not sure if there is a barrier here: only the realisation that one can apply, even if there is little relevant experience.	Encouragement to apply.
PC01	Pref:xxvii	Practice	Lanscape of practice	Unstated	A map that includes all the engineering possibilities that could provide effective solutions for a particular project and we can also imagine contours of difficulty. The low contours surround possibilities that are easier to achieve, the high contours include more difficult possibilities, and the boundaries mark the limits of feasibility.	Unknown to students	Students are only introduced to technical factors shaping the lanscape.	Confusion and resentment among engineers that decisions don't reflect technical priorities.	New concept	Discuss case studies and experiences of practice that reveal the interplay of both technical and socio-technical factors. For example when an engineering undertaking has to be performed by the "B" or "C" team, people who are inexperienced and unable to fully comprehend the technical implications of the work they are performing.
PC02	Pref:xxviii	Practice	Socio-technical factors shape the landscape of practice	Unstated	In engineering, the social and technical are intertwined, inseparable realities of practice.	Unknown to students	Students are only introduced to technical factors shaping the lanscape: therefore, other factors are labelled as "non-technical"	Clear view that anything that is not purely technical is "non-technical" and has little to do with "real engineering", leading to tendency to relegate all socio-technical work to secondary status.	New concept - socio-technical.	Reflection on kinds of activity performed in workplace - any activity that involves interactions with another person is socio-technical. Ask engineers to list activities in their daily work and classify as solitary / social completely non technical / socio-technical. The test for the second category is that anyone with no technical background at all or knowledge of technical issues could do it.
PC03	1:9	Fin	Why engineering provides value	Unstated	• To the extent possible in the time available, minimise the human effort and consumption of materials and energy needed to achieve a desired result, and, • Provide a reasonably accurate forecast of the technical and economic performance, the cost, and time needed, and be reliably able to deliver results within these expectations.	Little if any awareness		Difficulties in explaining the value contributed by engineering lead to engineers being marginalised, and not seen as "core capability" for the firm or organisation. This is reflected in the de-engineering of government over the last few decades. Could also explain low participation by women in engineering education, perhaps even practice as well.		The goldfields water pipeline provides a striking example, particularly the huge reduction in the cost of drinkable water. Before the pipeline was constructed, a day's supply of potable water distilled from local underground saline water cost 25-35% of a man's wages on the goldfields. After the pipeline came into operation, the cost was negligible propostion of daily wages.
PC04	1:19-20	Practice	Cost of employing engineers	Unstated	An engineering firm has to charge 5-6 times the hourly sum paid to an engineer to cover its costs.	Some students (only a few) may be told to use a "charge" rate to estimate cost of their project work, but would not understand how this rate is justified.	Students see finance and money issues as unrelated to engineering	Helps drive inappropriate prioritisation of work, and undermines ability to realistically estimate costs, see the value in re-using previous designs and plans		Many engineering companies charge out their engineers at considerably lower rates, citing market pressures. "We would not get any work if we charged a higher rate." However, this only happens when firms cannot produce sufficient value for the client to cover these costs. Ask students to collect information on charge-out rates and salary costs.
PC05	3:49-54	Problem-solving	There's much more to engineering than problem solving and design	Unstated	Solitary design and problem solving is usually less than than 10% of time, analysis & modelling is also less than 10% of the time (except for a few engineers). Expert engineers know how to avoid problems in preference to solving them. Problems without well-known, tried and tested solutions add to uncertainty.	Little awareness		Frustration, uncertainty (do you think the work is more technical here or somewhere else?), searching for other opportunities, frustration at not having much opportunity to use "skills for which I have been taught." Frustration and feeling of incompetence when confronted with challenges that require other styles of thinking and action.	Perception that other aspects of practice are secondary (from design and problem solving) inhibits willinglness to learn other skills.	Research evidence can help demonstrate reality, validating subjective individual observations. Increase focus on practicing delivery processes: planning, monitoring, risk management, safety.
PC06	3:54-9	Project management	Project life cycle	Sometimes mentioned	Sequential project life cycle: understanding requirements; negotiating scope; design and planning; cost and risk estimation; final investment decision; organising; project implementation (construction, commissioning, handover); project operations and sustainment; project closure, restoration, remediation, reuse, recycling; project evaluation.	Limited awareness		Mostly well-understood idea, appropriated reasonably quickly. However, engineers take time to appreciate the value and importance of project delivery, delaying the acquisition of appropriate skills and knowledge.		Ask students to write case studies on actual projects to reveal the details to themselves.

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PC07	3:60-1	Problem-solving	Engineering problems are rarely presented with complete information in writing	Contradiction	Engineering problems are rarely if ever written: engineers have to elucidate the issues through conversation and dialogue to comprehend the problem, even getting people to accept that there is a problem at all. The solution is often defined by the problem description that the engineer has to write. Ambiguity is normal, and complete information is almost never available. (See PC3.5)	Engineering problems will be completely specified in practice, in writing, with "problem statements". Leaving out important data or providing ambiguous information is "unfair". Problems need to have complete information, in writing, to be solvable. Verbal statements are "subjective" and unreliable.	Every problem stated clearly in writing (with images), and completely, with numerical (or symbolically defined) input parameter values.	Young engineers don't know where to start, need hand-holding, and don't develop skills needed to interact with clients to clarify the issues, discern client needs in terms of engineering possibilities, and develop project definition and scoping documentation.	Without knowing where to look, or how to use precedents, learning will be slow and difficult.	Encourage engineers to look for solutions to similar problems first, then engage the client in conversation to understand more about the problem. We have a checklist of issues that need to be discussed. It is relevant for machinery projects but could stimulate design of similar checklists in other displine areas. Most companies should have similar checklists.
PC08	3:61-3	Problem-solving	Logical explanations are essential and can be challenging to write	Contradiction	Solutions and conclusions require logical explanations so that they can be checked by others: most frequent serious errors stem from inappropriate assumptions or critical thinking mistakes, sometimes conceptual misunderstanding. Engineers save costs and provide better value if they can quickly spot reasoning errors and craft concise logical explanations that can withstand critical analysis.	Only a brief explanation of assumptions is needed, if any, since the lecturer (or senior engineer) will already know more than they do, and that mathematical derivations are self-evident. Verbal reasoning is "loose, qualitative and imprecise" compared with mathematical reasoning backed up with numbers.	Powerpoint presentations do not include explicit statements of logic and assumptions. Problem solution examples do not provide explanations. Mathematical equations are held to be "self-evident" and do not require logical explanation. Lecture note powerpoints also miss explanations, assumptions, only have sketchy diagrams.	Inability to detail implied assumptions, powerpoint reports do not explain logical connections, and importantly, qualifications on reliability of evidence. Illusion created by "sentiment of rationality" (William James), an emotional feeling of inner peace that is associated with the notion that something is self-evident and needs no further explanation. Challenged when presenting argument for new initiative: explanations not based on sound logical principles.	Beliefs about supremacy of mathematical logic inhibit development of verbal reasoning skills.	Philosophy studies, exercises in logical thinking, critical analysis of reports, practice in writing verbal logic and explanations, subjected to criticism by peers to build strength and reliability. Provide lots of worked examples showing logical argument, assumptions and conclusions. Reward explanations. Allow time. I have some sample exercises that can provide useful discussion pointers.
PC09	3:63-5	Problem-solving	Engineers have to work with missing and uncertain information	Contradiction	Most engineering situations are imprecise: engineers have to develop solutions without clearly defined input parameters. The cost of obtaining more precise information may make it infeasible to prepare more accurate estimates. There are often many solutions that can be made to work for about the same cost, but the total costs cannot be distinguished because of information gaps so there is no clear choice. (See PC3.3)	Engineers solve well-defined problems that have more or less complete specifications with a single best solution. Problems need to have complete information to be solvable.	Omission. Every problem stated clearly in writing (with images), and completely, with numerical (or symbolically defined) input parameter values. Student practice exercises can be open-ended but rarely have extensively incomplete or missing data.	Young engineers don't know where to start, need hand-holding. Engineers do not have well developed skills to identify missing information and develop reasonable assumptions.	Without knowing where to look, or how to use precedents, learning will be slow and difficult.	Changing value perception (reduce risk, value of precendents). Provide selected problems without input parameters, just the intended purpose. Students have to define input parameters.
PC10	3:66-7	Problem-solving	Most design is based on a precedent	Unstated	Design mostly involves modification of existing artefacts or designs. Design without precedent is rare, and can introduce unnecessary risks.	Design exercises start with blank sheet of paper, from scratch, with total freedom to design what you want without any major constraints. Creativity is associated with free unconstrained sketching. If it's based on an existing design, then it's just a modification exercise.	Students rarely have access to design libraries, and therefore can't use existing designs as starting point. Also lack opportunity to acquire library of design ideas.	Inability or reluctance to use precedents as basis for design. Less reliable designs. Minimal learning from past experience.	Negative perception of copying may inhibit learning: needs to be tested.	Value of precedent, experience of senior engineers, knowing how to ask for help. Design tasks that require modification of existing artefact, not design of something entirely new.
PC11	3:67-8	Problem-solving	Precedents provide some of the best guidance	Unstated	Precedents provide some of the best guidance for engineering solutions.	It is common among students to think that copying of previous worked problems is a form of cheating.	Reverse engineering rare (?). Design exercises rarely based on existing designs. Students copy illegally published material on-line, associating copying with cheating.	Working from ideas of others or previous designs seen as "cheating". Not invented here syndrome.	Negative perception of copying may inhibit learning: needs to be tested.	Value of precedent, experience of senior engineers, knowing how to ask for help. Design courses incorporate strong reverse engineering component. Students learn reverse engineering skills.
PC12	3:68-9	Problem-solving	Codes enable fast and efficient design	Unstated	Codes (requirements) and standards (recommendations and guidance) represent accumulated experience that other engineers have learned from experience with precedents. Following codes and standards saves time and reduces uncertainty, cost, and risk perceptions. Creativity lies in knowing how to work within constraints imposed bu codes and standards to achieve outstanding performance.	Codes and standards constrain designers: you have to comply with their requirements, inhibiting creativity.	Omission (with rare exceptions). Reasons for following code not explained: students see code and standards as a constraint, not a support. "You have to comply with…." Most academics never refer to codes and standards.	Reluctance to engage with codes and standards in small companies. Don't appreciate cost (time) needed to develop codes, standards.	Value of standards not appreciated, inhibits learning. (Perceptions need to be tested.)	Value of precedent (in form of code), experience of senior engineers. Time/cost savings through using codes. Adopt more use of standards and codes in courses.
PC13	3:69-70	Excel	Engineers program with spreadsheets	Contradiction	Most engineers write software code for Excel spreadsheets and macros with Visual Basic. MATLAB is normally only used by technical specialist firms.	Engineers use C or MATLAB for programming at work. Other packages like MAPLE, MathCAD and Mathematica are valued, though not so well understood. Programming is seen by many engineering students to be something that you get someone else to do in India or Eastern Europe.	MATLAB (and increasingly MAPLE/Mathematica) are computing media of choice for education.	Disinclined to practice programming skills, loss of capability, inability to work with Excel macros, reliance on software packages.	Lack of confidence inhibits learning, Excel not seen as a "serious" computing tool may also inhibit interest in learning.	Training courses are available. Provide challenges to reward students that learn to excel in Excel/VB
PC14	3:70-1	Problem-solving	There is never enough time to investigate everything	Unstated	Engineers have to make decisions without the time to find complete information, to handle every issue. Engineers have to decide quickly to devote attention to the most important issues and ignore others.	Engineers in professional practice do not have the pressure of assignments and lectures to attend, or part-time work to earn enough money. They can take all day to do calculations and check the results.	Most engineers learned to work with this reality during their university courses when there was never enough time to study everything needed to get a perfect set of grades (and enjoy life at the same time). Successful prioritising is something that most students learn, through informal methods.	Value perceptions shape prioritising in the workplace and indications from research suggest only a weak alignment of values with commercial imperatives.	Understanding value creation is an important pre-requisite here. Engineers do not (mostly) have well developed sense of commercial or social value, so that conceptual development must come first.	Prioritising time is a big issue for engineers. Once value perceptions are developed, then engineers can focus on tasks that create the most value, within the time available. Basic project management is also a pre-requisite, understanding how much time it takes to get desired results. PC48 also deals with mechanics of time management.

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PC15	4:83-6	Practice	Ability to learn from others	Unstated	Expertise is easier to build by seeking out people who can critically evaluate performance and offer critque and suggestions for improvement	Unknown to students		Most clearly seen among novices who prefer asking each other for help rather than seeking out experienced people who could help them much more. Afraid to appear stupid in front of others.		Ask students to nominate knowledgeable and skilled individuals who could provide the kind of feedback they need to improve their performances: they will probably need to think of 5-10 people to cover different aspects of the performances they want to improve. Then they can start to develop relationships with these people.
PC16	4:86-7	Practice	Ability to evaluate own performance	Unstated	Research on expertise reveals how important it is to be able to evaluate your own performance in order to acquire the attributes of an expert engineer.	Unknown to students		Little emphasis on this in education leads to inability to self-assess performance in workplace. Females tend to under-estimate their performance, and males tend to overestimate (from reading of literature only)		Discuss different techniques that might be applicable for self-assessment of their performances. Discuss 3-5 different performances.
PC17	4:87-9	Practice	Deliberate practice, persistence, resilience	Unstated	Deliberate practice, according to Ericsson, is an effortful problem-solving activity in which the performer constantly struggles to achieve a higher level of performance by evaluating his or her current level of performance and then adopting deliberate changes in technique to see whether they open up the possibility of higher levels of performance. To do this, the performer has to work at his or her ultimate levels of skill.	Unknown to students		Lack of awareness blocks opportunities for self-improvement.		There are many Youtube videos that provide insight into deliberate practice. Malcolm Gladwell, a New York journalist, wrote a book about this and appears on several videos. Ask your students to find a good video.
PC18	5:99-102	Practice	Engineering enterprise	Unstated	An organisation that depends on the application of specialised knowledge that emerges from engineering schools and allied communities of practice. An enterprise is not the same as a firm or company. The people involved can come from several different firms, all collaborating with the same purpose – delivering a product, a service or information.	Unknown to students		Inability to understand how engineering affects product and service delivery.		How do we define engineering - ask your students to discuss this, and then see how they react to the idea of an engineering enterprise.
PC19	5:103-9	Practice	Knowledge types	Unstated	Knowledge types: explicit (codified, propositional), procedural, implicit, tacit, embodied, contextual.	Unknown to students		Lack of awareness blocks acquisition and appreciation for unwritten knowledge, leading to devaluation of practice knowledge, arrogance towards technicians and artisans, and ultimately frustration and inability to deliver high quality technical outcomes. This is often the reason why engineers are seen by trades and technicians as impractical and ignorant.		I have used examples such as asking two students to walk towards and past each other without colliding, and then asking them to explain how to do that in words. That illustrates the idea of tacit knowledge "is more than we can tell". Ask them to find examples of each kind of knowledge from their own practice experiences.
PC20	5:109	Knowledge	Competency depends on knowledge from other people	Contradiction	Competency comes from an individual's ability to work with objects, tools, materials, artefacts, and documents that embody knowledge from other people (e.g. Procedures, checklists, standards, manufacturer's catalogues, design guides, distributed expertise etc.), and also the ability to collaborate with other people with knowledge and skills.	Competency is an attribute of an individual. Individual assessment reinforces this notion, also statements of engineering competency used in accreditation.	Marks and grades are almost always awarded for individual performance (usually in writing or identifying correct written responses).	Misunderstanding of value of process, procedures, and documentation. Frustration, loss of capacity, loss of quality and productivity caused by resistance to process-drive npractice.	Individual competence is deeply embedded in human resources culture, making it difficult to learn about social and cultural competence.	Latour's illustration of a supermarket could be useful. Also our (now) built in IT infrastructure and GPS navigation for finding our way around. Compare with 3rd world city with no street signs or maps. Require use of procedures, standard, codes, design guides, checklists to demonstrate how these contribute to performance.
PC21	5:110	Knowledge	Knowledge is difficult to learn and transfer	Unstated	Acquiring these kinds of knowledge, either for oneself or helping others acquire them, is time-consuming and troublesome. Implicit, tacit and contextual knowledge cannot be represented with external objects and hence are even more difficult to acquire or transfer from one person to another. This limitation becomes crucially important in engineering practice.	Unknown to students		Undermines engineers' ability because they waste time trying to acquire knowledge that could be more easily delivered by skilled performances by other people.		Students with industry experience can probably provide plenty of examples to illustrate this.
PC22	5:111	Knowledge	Knowledge influences perception and action	Unstated	Knowledge that influences perception and action is in the minds of people.	Unknown to students		Young engineers waste time trying to find information for themselves, and don't stop to think "who might know this, or at least know where to look?"	Time wasted on searching for information	Understanding concept of distributed expertise, developing social skills, building trust, restoring people to centre of practice
PC23	5:111-115	Knowledge	Mapping engineering knowledge	Unstated	We can map the knowledge used in engineering work, the knowledge needed by people who influence the operation of engineering enterprises, including those who work in them. A significant part of the knowledge exists in the minds of people other than engineers.	Unknown to students		Undermines engineers' ability to appreciate the span of knowledge required for a successful project.		Practice exercise 2, p146.

Number	Page Refs	Category	Title	Type	Engineering practice: observation	Perceptions by students	Education factors	Practice impact, consequence observed	Impact on learning, barriers	Intervention strategies
PC24	5:132-7	Knowledge	Distributed expertise	Unstated	Engineering expertise is distributed: knowing how to leverage distributed expertise is more important than any specific knowledge. can only be accessed by arranging for the people who have the knowledge to contribute it through skilled and knowledgeable performances. (cf I.02, M05.01, PC05.08)	Unknown to students	Marks and grades are almost always awarded for individual performance (usually in writing or identifying correct written responses), not for collaborating with other people and leveraging their knowledge.	Urge to develop own skills at expense of developing skills to be able to tap expertise of other people, inability to see potential ways for others to contribute and help, "I could do it faster myself".	Inability to understand idea of socially constructed knowledge, that other people contribute to an individual's capability.	Understand how people collaborate in engineering. Identify different kinds of knowledge and expertise used in achieving intended goals. Students learn to build their own performance by seeking help of others, including technicians, peers and outsiders.
PC25	5:138-9	Knowledge	Knowledge is carried by people	Unstated	Engineers rely on others to provide know-how and expert advice when needed. Experts take much less time to figure out what kind of expertise is needed, and it is much quicker and more effective for an expert to perform the work than to learn how to do it from an expert.	Knowledge is written: knowledge that is not written does not count.	Asking someone else is like cheating. You are supposed to know it all and be able to do it for yourself. Even if I don't know it I ought to know where to locate it in a book or on-line source.	Young engineers waste time trying to find information for themselves, and don't stop to think "who might know this, or at least know where to look?"	Time wasted on searching for information	Understanding concept of distributed expertise, developing social skills, building trust, restoring people to centre of practice
PC26	5:139-140	Knowledge	Value of unwritten knowledge	Contradiction	Engineering relies as much if not more on unwritten knowledge and tacit knowledge than explicit written codified knowledge. Written knowledge cannot influence action until a person has appropriated (acquired) the knowledge in their head.	Knowledge is only valid if it is written. Other kinds of knowledge are "subjective" and of less value.	Marks and grades are almost entirely based on assessment of written explicit knowledge (examinations, tests, quizzes). Marks based on performance (e.g. creating a sketch, quality of a manufactured item, use of appropriate technique) are often regarded by students as "subjective".	Inability to comprehend, appreciate the value of, and access unwritten know-how, typically carried in the minds of experienced technicians and other workers. Early attempts at knowledge management reveal this thinking.	Inability to understand or appreciate unwritten knowledge inhibits learning related to experience. Ability to acquire experiential contextual knowledge is not uniformly distributed.	Understand different kinds of knowledge, ways of knowing: requires appreciation of people in engineering. Assess tacit and unwritten knowledge through performance and electronic testing instruments developed at UWA.
PC27	5:140-143	Knowledge	Distributed cognition	Unstated	New engineering knowledge emerges from the social interactions between people with complementary knowledge, working on similar issues together.	An engineering hero solves the problem by himself, at the last moment.		Not understanding this makes it more difficult to engage in social activities that can stimulate knowledge creation and learning. For instance, understanding that technical disagreement is really a negotiation could open up much more effective solution pathways.		Reflection and work-related case studies might provide some good examples. Look for ideas that emerged as a result of social interactions.
PC28	5:143-4	Knowledge	Social relationships lie at the core of technical engineering	Unstated	Even the most technically oriented engineering work rests on a network of personal relationships. In fact, the more specialised and narrow the field of technical expertise, the more engineers will rely on relationships with other people to provide all the other knowledge and expertise that they need for their ideas to reach fruition.	Learning about social interactions and building relationships has nothing to do with engineering		Engineers devalue social relationships in practice, creating obstacles to the development of their technical capabilities. Self-image is key here: engineers need to appreciate that, like any aspect of expertise, relationship skills can be learned and developed, with deliberate practice.		
PC29	6:156-160	Collaboration	Perceiving reality requires us to understand how prior knowledge can help us and deceive us	Unstated	It is very difficult to make sense of the world without some prior belief, an expectation about what we are experiencing. Yet, the same expectations and beliefs that help us make sense of the world also prevent us from seeing reality and learning where our expectations are wrong.	Unknown to students		Listening skills and seeing skills are not well developed in graduates, from author's informal observations. Influence of prior knowledge is not appreciated. Engineers' learning potential is therefore limited by these significant deficiencies in perception abilities. This helps to explain why so few engineers currently develop to become experts.		
PC30	6:160-1	Collaboration	Engineering is based on accurate perception skills	Often missed	Engineers need highly developed perception skills. For example, visual skillsare needed in order to notice subtle features in artefacts (e.g. cracks, crazing, distortion, slight defects), and unusual features in graphical information displays (e.g. unusual data trends on a graph). The ability to read drawings, a capacity for spatial imagination and visualization abilities, is also critically important. Expert engineers also know that sketches, graphics and drawings are often useful ways to help convey intent and meaning to others, but the ability to prepare sketches depends on seeing accurately.	Visual communication is all about preparing fancy images and graphics, whenever possible by copying and pasting from the internet. Sources include Google images and clipart sites. Engineers use CAD for anything more complex.	Emphasis is on transmission, not reception (seeing, perception skills). Absence of building visual communication skills as means to convey intent.	Frustration related to communication probems is amplified by less than properly developed visual communication and listening skills, inability to read drawings, inability to communicate with sketches.	Inhibits learning that requires visual perception (non-text), may inhibit spatial awareness	Drawing on right side of brain, freehand sketching practice, understanding visual perception models
PC31	6:163-171	Collaboration	Listening starts with engaging the other person	Often missed	Ability to be able to listen accurately and take notes in order to capture as much detail about the words actually used by the speaker and what they said.	Usually unknown to students		Listening skills are not well developed to start with, as explained in Ch6.		
PC32	6:171-4	Collaboration	Listening accurately and taking notes	Often missed	To be able to listen accurately and take notes in order to capture as much detail about the words actually used by the speaker and what they said.	Usually unknown to many students: some (minority) practice good note taking skills		Most graduates seem to have inefficient note-taking skills and tend not to take notes, thus significantly restricting their ability to learn from others.		
PC33	6:174-5	Collaboration	Contextual listening	Often missed	Lucena: listening facilitates meaning making, enhances human potential, and helps foster community-supported change.	Usually unknown to students		While advocated by leading researchers, the problems evident from misdirected engineering projects probably reflect poor skill development in listening. The evidence shows this could be fixed.		

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PC34	6:175-6	Collaboration	Helping others to listen	Sometimes covered	Applying knowledge of listening skills to help other people listen to explanations and presentations			Engineers' frustration often reflects their inabililty to notice when other people have "shut down" and are no longer listening.		
PC35	6:183-7	Collaboration	Developing seeing skills by sketching	Unstated	Seeing' is an active process that you can improve by training and practice. It is a state of mind that requires discipline and the ability to put aside distractions and preconceived ideas. The quality of our sketching, therefore, reflects our ability to see.	Usually unknown to students		Since freehand sketching is limited to just a few courses, it is likely that most engineers miss out on the benefits. Again, in most courses, the emphasis is on communicating to others rather than improving seeing skills.		
PC36	7:196-9	Collaboration	Communication is how people collaborate	Contradiction	Communication is the means by which people interact in order to collaborate. Human behaviour is guided by perceptions: communication enables us to modify perceptions and hence actions.	Communication is information transfer. Communication skills only include technical writing and graphics for presentations. Communication is learned through practice and cannot be taught. Other communication skills only needed if you become a manager.	Communication skills for which students gain marks are based on writing and, on rare occasions, by speaking. Powerpoint presentations sometimes gain marks.	Misplaced confidence in communication skills, inability and resistance to learning interpersonal communication and collaboration skills.	Belief that communication is something neded by managers inhibits willingness (of engineers) to learn, belief that interpersonal communication skills are "innate" inhibits willingless to learn. "I will need to learn later, when I become a manager."	Undestanding people in engineering practice, demonstration of listening capacity improvement by others, research evidence on importance of listening, impotance of perceptions. Case studies that reveal how perceptions, not necessarily facts, guide engineering decision making.
PC37	7:199-201	Collaboration	Technical communication relies on technical understanding	Assumption, unstated	Communication is essential technical skill: communicating effectively in the context of technical work is highly specialised and difficult to learn.	Communication is a non-technical subject: it is not core to engineering.	Communication is assessed separately from technical capability, mostly. Frequently stated that communication is a non-technical competency.	Engineers often demonstrate poor communication abilities.	Seen as peripheral to "real engineering" and therefore of secondary importance. 'Technical drawing' has been seen as something peripheral but worthy of study, though.	Understand social development of engineering knowledge. Communication is part of the technical business of engineering.
PC38	7:201--211	Collaboration	Engineering is a series of collaboration performances	Unstated	As explained before, an engineering enterprise is a large collaboration performance by many people. In fact, as explained by the concept of a 'value chain' in chapter 5, engineering enterprises collaborate (and often compete at the same time) with each other.	Usually unknown to students		Engineers find it hard to appreciate what is happening for most of their working days, for example, one described this as "random madness" and most see their collaboration efforts as "not real engineering", something that gets in the way of doing the engineering part of their job.		
PC39	7:212-3	Collaboration	Technical coodination dominates engineering practice	Unstated	Coordination, gaining alignment, willing and conscientious collaboration, support/engagement of senior staff, dominates engineering practice, taking 25-30% of engineers' time and effort.	omission: "that admin kind of stuff"	Students don't appreciate (are not taught) that coodination takes time.	Engineers experience frustration, schedule slips, and unexpected results from other people because of lack of coordination skills, inability to allow time for coordination. This adds up to loss of productivity, and engineers regularly report feeling stressed, and working unnecessary long hours. "It would have been easier to do it myself." A phrase often heard in interviews.	Non-existence inhibits perception that it can be learned (even after 30 years).	Demonstrated research, presence of people, people skills, effective models. Require students to observe processes and use of time in teamwork assignments to reveal coordination component: part of assessment o make it visible.
PC40	7:213-5	Collaboration	Engineers teach	Unstated	Making sure that other people have learned something new requires much more than an explanation. Consistent monitoring of their subsequent performance is essential to make sure they have understood and are acting in accordance with expectations. Misunderstandings are common and have to be patiently overcome.	Teaching other people requires a concise, simple and logical explanation, or a PowerPoint presentation. Presenting information is sufficient for people to learn it.		Given that engineers regularly report frustrations in explaining technical ideas to other people, even getting peers to understand and appreciate ideas, this is almost certainly related to teaching inadequacies and misconceptions such as "logical explanation should be sufficient." Unfortunately, current teaching practice in engineering schools does not provide a useful model for them.		
PC41	7:215-6	Collaboration	Negotiation	Unstated	Engineers negotiate for time, resources, space and other virtual spaces such as performance margin to make their work possible (or less difficult).	Usually unknown to students		Research (by Itabashi-Campbell) has highlighted the parallels between technical problem-solving and negotiation. Few engineers (unless they have studied negotiation in business training) have any appreciation on how to negotiate effectively.		
PC42	7:216-8	Collaboration	Vocabulary and jargon	Introduced	Engineers use technical jargon. Many common English words carry different meanings and sometimes very different meanings, making it difficult for others to follow a converation.	Students learn technical jargon but have difficulties distinguishing it: they refer to speaking in "plain English" as a way of avoiding jargon, though they find it very difficult to do this.		Engineers know that their "jargon" is difficult for others, and talk about speaking in "plain language" to non-engineers. However, few if any understand how words mean different things to different people in different contexts, and have a naïve belief that meanings of words are fixed and standardised.		
PC43	7:218-20	Collaboration	Culture – habitual ways in which people interact socially with each other	Unstated	In every social setting, people interact with each other in more or less predictable ways. As human beings, we establish 'social norms', habitual ways of greeting each other, helping each other, influencing each other, meeting strangers, taking joint decisions, forming and maintaining friendships, speaking with each other.	usually unknown to students		While engineers have an intuitive appreciation for culture, and can see the differences in organisational culture, few have the observation skills to identify and allow for cultural differences.		

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PC44	7:220-8	Collaboration	Language is context, time and person dependent	Contradiction	Language is context, person and time dependent: engineers use a dialect of English with many meanings at variance from common English. It is useful for engineers to understand that language conveys time- and person- dependent meanings that depend on prior experience and understanding.	Omission, reliance on reference definitions, standards. Belief that "It must be my fault if I didn't understand the problem" Another manifestation is describing the importance ascribed to crafting the text so that misunderstandings are impossible.	Language is absolute: every word has a defined meaning, with reference to the text.	Frustration - "this company is run by accountants", inability to work effectively with others. Undue emphasis on written statements of intent with belief that thay can't be misinterpreted. Inability to forecast ways in which others will interpret differently. Asserts that it is difficult or impossible to have a conversation without agreement on meanings.	Belief in precision of language inhibits ability to learn.	Understanding concept of distributed expertise, developing social skills, building trust, restoring people to centre of practice, understanding construction of mental models. Encourage students to pick out Engineering dialects (dictionary available on request). Explore and value multiple interpretations, doubts and uncertanties.
PC45	7:228-232	Collaboration	Conveying intent accuratly is difficult	Unstated	Conveying intent accurately is a time-intensive, step-by-step, iterative, interactive process with close analogies to teaching. Difficult and challenging. Note also I.16 technical coordination, gaining alignment and willing, conscientious collaboration - similar but different. Conveying intent is a part of I.16.	Something that has been explained concisely and logically needs no further explanation. Presentation (transmission) is all that is needed. "It must be my fault if I didn't understand the problem" Another manifestation is describing the importance of crafting the text so that misunderstandings are impossible.	Emphasis is on presentation of information - presentation skills are valued, not teaching skills.	Difficulties in conveying intent. Frustration when results of work ignored, misunderstood, implemented incorrectly, not understood, inability to transfer solutions to other people, constraints on effectiveness. This company is run by f____ accountants: they can't understand the simplest engineering issues. They just don't get it."	Simplistic notions of information transfer inhibit learning of more effective methods	Understanding concept of distributed expertise, developing social skills, building trust, restoring people to centre of practice, develop pedagogical skills and technical coordination skills. Learning to teach effectively with a scholarly understanding of constructivist learning theory can be very helpful.
PC46	7:233-4	Collaboration	Teams outperform individuals because of diverse interpretation	Contradiction	Teams outperform the same number of individuals working separately by exploiting the diversity in knowledge, interpretation and thinking of their members. This enables better ideas to emerge from social interactions and working together.	Teamwork means dividing the work into sub-tasks to be performed individually by team members and assembled at the end. Teamwork requires tedious meetings that waste too much time and even require you to get dressed and travel to the campus: traffic delays and parking hassles costs extra time. Individual effort is not rewarded, and many times, almost everything is done by one person.	Students work in groups, and it is assumed that team skills develop by practice alone. Academics believe that team skills can't be and should not be taught by engineering academics. A couple of lectures on team skills by an expert is all that is needed. Students dislike team projects because marks are usually equally split between group members so individual effort is not rewarded. With students able to choose their own work groups, they can work strategically and often agree to split work effort between units -"I'll work on that project if you cover me for this one."	Inability to make use of team work when appropriate, preference for individual work, interactions relegated to secondary priority, lack of attention to relationships	Implicit devaluing of team skills in education (because they don't need to be taught) inhibits learning later.	Understanding concept of distributed expertise, developing social skills, building trust, restoring people to centre of practice, understanding construction of mental models. Understanding about diversity of mental models underlies belief in power of team work. Set exercises that require teamwork: reward constructive team behaviour.
PC47	7:235	Collaboration	Engineers spend time listening and talking	Contradiction	Engineering team work is more effective when team members have complementary technical and commercial expertise, and are talking and working together to build cooperative relationships and trust. Helps informal leadership, even in absence of authority. Engineers spend around 60% of the time on direct social interactions.	Good engineer works quietly away without talking. "Non loqui sed facere".	Team projects are usually (but not always) scheduled so teams have to meet in their own time. Team meetings are therefore seen as an extra "overhead" and "time commitment" rather than a process intrinsic to team work. Verbal and listening skills are not taught. Student teams have largely same, not complementary expertise. Set practice exercises mostly do not require teamwork. We mostly require individual work: students are silent in lectures and work in silence in tutorials. Regarded as a non-engineering, management issue.	Lack of attention to team work, prefers to work alone, finds collaboration difficult, insufficient time allowance for building trusting relationships, lack of importance placed on social relationship building (seen as time wasting).	Weakness in verbal skills (which get worse with increasing education in engineering, at least in terms of perceived importance by students), inhibits learning of teamwork skills.	Understanding concept of distributed expertise, developing social skills, building trust, restoring people to centre of practice, understanding construction of mental models. Cooperative learning groups, reciprocal teaching, jigsaw learning (Brown et al 1993)
PC48	7:236-9	Collaboration	Smart use of email and calendars	Unstated	A response to a written message requires time to write, and can easily be misunderstood, in fact is almost certain to be misunderstood. Expert engineers know how and when to respond effectively. Smart engineers reserve time int heir diary or calendar for solitary work.	It is necessary to respond to any electronic messages and emails immediately. Minimal use of calendar or diary.		The longitudinal study, using personally addressed emails, demonstrated that 50% of engineers are happy to allow researchers to take their priority time, responding within 12 hours. Anecdotal evidence reveals inadequate time management skills by many engineers, reporting very long hours on occasions. Many find it difficult to say "no" when they need to.	Habits (not necessarily good ones) can develop over years of undergraduate study - few students use a calendar except for their lecture and class times. Most lack experience with formal use of e-mail. Time is structured throughout education, but can be almost completely unstructured in the work environment. Engineers are mostly autonomous and few(currently) develop systematic ways to handle routine tasks.	See PC14 for prioritising time based on value creation. The work of Leslie Perlow (Time Famine) is useful here. See text. Can set exercises in observing time utilisation, task duration, interruptions, etc. Identify times when uninterrupted time is available to focus.
PC49	7:239	Collaboration	Email seldom resolves conflict	Unstated	When there is any conflict, or emotional arousal, there is much more likelihood that any message will be interpreted in a way that further inflames feelings of conflict.	Email and text messages are quick and convenient and you don't have to look a person in the eye when you need to convey bad news.		This is not appreciated widely, though most engineers don't engage in email conflict. The few that do, however, seem to have no appreciation for the damage it can do to an organisation.	Students and engineers often have simplistic models of communication and may not distinguish between different communication channels - "surely the message is the same no matter how it is transmitted."	Engineers will time and encouragement to distinguish different communication genres and understand the patterns of collaboration (or occasionally) conflict that accompany them.
PC50	7:240-1	Collaboration	Management systems	Unstated	Larger engineering enterprises use many formal techniques to coordinate collaboration performances such as written organizational procedures and, increasingly, software such as project management systems (e.g. Primavera, Microsoft Project) and large enterprise resource management (ERM) systems (e.g. SAP).	Usually unknown to students		Few engineers appreciate why extensive management systems are used, seeing them as administrative "impositions" by managers rather than tools to be used. The one exception, possibly, is project management, where the use of software tools is widely appreciated.	Like other aspects of communication, engineers treat it as "information transfer" and so a management system transmits information as well as any other means. However, this is not what happens in practice.	Sule Nair (unpublished manuscript) and Leonie Gouws both explored maintenance management systems, helping to expose complex socio-technical issues that interfere with human coordination, and undermine the benefits that these systems should be able to provide. It can be helpful for engineers to understand these limitations, at least at a superficial level, so that they understand what management systems can and cannot do.

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PC51	8:252	Collaboration	In planning teaching, the learning objective is performance	Unstated	Teaching has to start with the idea that the learner or learners are going to have to accomplish a performance with the help of their learning. It may be giving you approval to do something. It may be that they are going to implement some of your ideas in the form of new artefacts or systems.	Usually unknown to students		This refelects difficulties in conveying intent. Frustration is apparent when results of work ignored, misunderstood, implemented incorrectly, not understood, inability to transfer solutions to other people, constraints on effectiveness. "This company is run by f____ accountants: they can't understand the simplest engineering issues. They just don't get it." Engineers see communication as information transfer, and don't appreciate that the purpose of transferring information is the subsequent performance by someone using the information.		
PC52	8:252-8	Collaboration	All learning is based on prior knowledge	Unstated	Prior knowledge has to be activated, sufficient, appropriate and accurate for learning to take place. We need to know about the language used by the learner, we need to know about the ideas already in the mind of the learner on which we can build and third, we need to ensure that the prior knowledge has been activated, brought to the foreground of the learner's mind.	Usually unknown to students		Not explicitly appreciated by engineers: could be a very helpful concept.		
PC53	8:267-72	Collaboration	Value, interests, expectancy and environment: motivation for learning	Unstated	Motivations for learning are strongly related to the value that learners perceive they will gain from learning, how well the learning serves their immediate interests, how well they think they will be able to perform the learning tasks, and the degree of emotional support they expect to receive (the environment).	Usually unknown to students		Engineers dismiss inexplicable reactions by people or what they see as deliberate influencing behaviour as "politics", something they think they are above. Understanding this behaviour in terms of value conflicts might be help engineers engage more constructively.		
PC54	8:272-277	Collaboration	Delivering the message in teaching	Unstated	By addressing learners' interests and prior knowledge, we can develop the explanations that learners will engage with. For each concept, identify the invariant and variation components and draw attention to them within what learners can cope with in a single session.	Usually unknown to students		As explained elsewhere, difficulties in teaching lie behind comments such as "They were brilliant at devising solutions, but hopeless at transferring those solutions into operating plants."		
PC55	9:292-302	Collaboration	Technical coordination process - organising & negotiation, monitoring and completion.	Unstated	Technical coordination is process of gaining willing and conscientious collaboration to perform technical work to an agreed schedule, usually with the aim of a peer contributing knowledge in the form of a skilled performance.	All that's needed is to send request for work to be done with details attached.		Most engineers see this as fire-fighting, but behind the apparent chaos, there is order. By understanding patterns, engineers should be able to improve their coordination performances.		
PC56	10:322	Uncertainty	Reliable performance requires a high level of predictability	Contradiction	99.99% predictability required (or more) for reliable performance.	50% is OK to pass, 70% is a distinction. Getting it 100% right is for nerds.	Error control, quality assurance, elimination of errors - not mentioned in education. Students are conditioned to accept 50% right is passable, 70% is distinction. No understanding on how we can achieve 99% or better in practice.	Checking and review work relegated in priority or not done, casual approach to checking, inability to see the need for checking, loss of quality, errors, loss of control over time schedule as error consequences manifest themselves as unplanned overruns	Not seems as something to be learned - just follow the error checking procedure.	Understand centrality of people, and reliance on human actions and thinking. Perception differences lead to different understandings that can become errors. Build in peer review, draft review, assistance and other processes at selected opportunities so students know how an error-free performance can be achieved.
PC57	10:322-4	Uncertainty	Uncertainty in engineering mostly arises from unpredictable human behaviour	Unstated	Uncertainty is mostly due to unpredictable differences in human interpretation, subsequent actions, and timing.	Uncertainty is probability, most often following a statistical normal distribution.	Treated only as a statistical phenomenon, often a minor issue in the course. "Noise", "Signal to noise.", Component failures. Uncertainty is only ascribed to inanimate causes. People can be kept in line with fences, gates, signs, warnings, laws.	Inability to plan for human error, has difficulty preparing robust plans that take risks and human behaviour into account.	Lack of people knowledge, invisibility of people.	People in engineering, diversity, unpredicatbility, value from reducing uncertainty. Planning/observation exercise, inclusive list of possible causes for deviation from plans. Examine this in context of student projects and assignments. Explicit understanding of human variablility.
PC58	10:324-5	Uncertainty	Human diversity can help reduce behavioural uncertainties	Unstated	As an example, systematic checking is essential and best done by another person as they see things in a different way. This helps expose alternative interpretations and reduces the chance of undetected mistakes and hence increases value by reducing uncertainty.	Checking is just a chore that takes away valuable productive time. If you check more, you will only find more mistakes.	Not mentioned. All checking (marking) performed by staff (who describe marking as a chore); happens after student task finished.	Checking is regarded as a chore that does not add productive value, not part of the engineering process, something that happens later. Relegated in prority, "tick-the-box" task, delegated to junior staff, or skipped altogether.	Perception that checking is non-productive work and not part of the engineering process inhibits learning.	Change uncertainty/value perception, people intrisic to engineering, thinking diversity leads to mistakes. Introduce peer review and checking of assignment submissions.
PC59	10:325-7	Project management	Project management is reliable delivery in the presence of uncertainty	Unstated	Project management means leading and guiding people to faithfully translate technical ideas into engineering reality in line with project objectives.	Project management consists of planning, preparing a Gantt chart, and is largely an administrative non-technical function, something that anyone who can't handle technical stuff can do.	focus on applications of computer, mathematical analysis, restricts attention to planning: CPM/PERT.	Engrs see PM as non-technical admin overhead (meetings), scheduling is separate, something that junior people do. You become a project manager if you can't do the technical stuff.	lack of people awareness inhibits learning, something that non-technical people do.	People awareness, value perception (reducing uncertainty) can facilitate understanding. Teach project management in context of delivery task (e.g. Major design project).

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PC60	10:327-8	Collaboration	Written knowledge needs to be learned	Unstated	Providing information in documents, no matter how well they are written, is often as good as keeping the information secret. The information can only influence actions when it is in people's heads, and that requires learning.	Tacit assumption: once written and disseminated, written knowledge is available to be acted on. "I sent it in an email: that's sufficient."		Since communication is seen as information transfer, sending information in writing is also seen as the reliable way to do that. Many engineers see it as the recipient's fault if they don't read the emails, even though recipients may receive 200-300 emails a day.		
PC61	10:328-9	Project management	Project management performances can be improved	Unstated	Evidence shows that engineering projects, particularly large ones, have a poor record of success. Over $1Bn, the success rate is around 33% or less.	Unknown to students		Evidence presented in Ch11.		
PC62	10:329-30	Project management	Project management language shapes behaviour	Unstated	Project managers have evolved their own language, with terms such as resources, drivers, front end, FEED, FID, execution, etc. Labelling people as resources can make them behave like inanimate resources which only move when pushed.	Unknown to students		Evidence for this comes from research on maintenance systems. Technicians who are described as "resources" display minimal cooperation in entering data into CMMS, despite being highly competent with computer systems when they need to use them for their own needs.		
PC63	10:330-49	Project management	Developing a project plan, a living document	Basic coverage	Define and negotiate the scope, budget, time schedule, work breakdown structure, seek approvals, etc.	Basic awareness among students		While novices know that project management is important, few if any can do it well and remember everything that needs to be done. Senior engineers complain that novices and junior engineers have poorly developed project management skills		
PC64	10:335-9	Project management	Specifications	Unstated	Specifications are critical technical documents. There are two basic forms: a method specification that details the process to achieve an objective, and a test specification details the tests and inspections that will prove that the objective has been reached.	Unknown to students		Few novices, certainly almost no graduates, have any idea how to write a specification document. If they have to do it, they copy and paste from existing documents,. Without such understanding, they allow suppliers to exploit specification weaknesses, undermining technical and performance outcomes from projects.		
PC65	10:349-59	Project management	Risk assessment and management: working with uncertainty	Basic coverage	Identify risks and opportunities that influence project outcomes, causes and consequences, controls (avoid, accept, reduce probability, reduce consequences, transfer).	Students only have limited understanding of uncertainties and prefer numerical approaches.		Although novices and many graduates can go through the motions of risk management, there is little understanding of uncertainties and how they arise. Once again, copy and paste from earlier projects is a common way to achieve the results.		
PC66	10:359-60	Project management	Approvals	Unstated	Because of past failures, engineers now find themselves under detailed scrutiny by government regulatory agencies, mostly employing engineers. Engineers today find themselves devoting considerable effort in writing applications seeking approval for their projects from government agencies.	If any awareness, seen as administrative paperwork.		Engineers often encounter difficulties with approvals, and regard regulators as bureaucratic with nonsensical requirements that take valuable time away from the real project work. Engineers could make the business of gaining approval for projects much easier, by thinking differently, and putting themselves in the shoes of the regulators.		
PC67	10:360-4	Project management	Monitoring is a cyclical process	Unstated	Monitoring is essential to track progress and identify deviations from predicted schedule.	No awareness		Although there is lots written on project planning, much less has been written on monitoring progress in projects and systematic methods for assessing actual (as opposed to reported) progress.		
PC68	10:364-5	Project management	Contract variations	Unstated	Significant changes in the project plan that require new work, or rework that was not allowed for in the original estimates.	No awareness		Many engineers attend contract management courses to learn about variations and other contractual issues.		
PC69	10:365-8	Project management	Project completion is also a cyclical process	Unstated	A project is completed when all the agreed objectives have been achieved and accepted by the client. Completion is relatively straightforward if the project definition phase included all the necessary details on how completion of every task was to be certified, with appropriate acceptance tests and inspections.	Limited awareness: students regularly compromise on deliverables knowing that they can still gain a pass mark.		Completion is often misunderstood by engineers anxious to avoid unnecessary paperwork. In doing so, they risk allowing contractors and project managers to transfer liabilities from the project to the owning organisation later on, at great cost to the owners.		
PC70	11:372-4	Finance	Engineering needs money from investors	Unstated	Finance enables engineering. Engineering relies on investment from people. The cost of finance and amount available depends on risk perceptions of investors.	Finance is a business or management issue, not engineering: engineers only have to think about the budget they have been given.	Omission, rarely treated, though some references to time value of money.	Engineers are challenged when responding to business needs, they see this as a management issue for someone else.	You study that in an MBA.	Understanding people, risk perception / timescale/ amount at risk. Expose students to fundamentals of investment markets, and link investment risk to engineering risks.
PC71	11:374-6	Finance	Value is subjective	Unstated	Engineers associate 'value' with precision, certainty, knowledge. They find it difficult to think about commercial value.	No awareness	Value is constantly referred to in context of mathematical variable, the value of x, for example.	Research has shown that engineers mostly have difficulty in understanding, appreciating, or explaining financial value.	Prior exposure inhibits ability to learn	TBA
PC72	11:376-9	Finance	Time changes the value of money	Introduced	Inflation (or deflation) causes prices to rise (or fall) each year, decreasing (or increasing) the value of money in relation to common goods.			Engineers have limited understanding of this concept and tend to see monetary value as fixed and determined by the face value of the currency.		

Number	Page Refs	Category	Title	Type	Engineering practice: observation	Perceptions by students	Education factors	Practice impact, consequence observed	Impact on learning, barriers	Intervention strategies
PC73	11:379-84	Finance	Net Present Value	Briefly covered	In comparing projects, we discount future expenses and income at a rate determined by the cost of capital for this class of projects			While many graduates have learned to do the calculations, few understand the reasoning behind the calculations, and how a discount value is chosen.		
PC74	11:384-93	Finance	Accounting for costs, capital and operating expenses	Not covered usually	Details in book	Students often include only some component costs, ignoring labour content and capital costs		Research reveals a significant gap in engineers' appreciation of expenses - they only appreciate the direct cost of labour, and tend not to take the indirect costs into account.		
PC75	11:393-99	Finance	Cost depends on policy drivers	Unstated	Estimating the cost and time to complete a project is anything but simple. Engineering projects inevitably trade-off four main policy factors: quality, scope, schedule and cost. The appropriate trade-off needs to be chosen to match the objective and client needs.	Estimating the cost and time to complete a project is a relatively simple aspect of engineering. It is simple because faculty staff don't see the need to teach it. You only need to be able to add up a column of numbers.	Students have little if any exposure to financial issues, even the relative costs of labour, materials and components. However, it is possible that they develop an intuitive notion of the compromise issue when faced with pressing deadlines for assignments.	Many engineers do seem learn this effectively, after some time, but may not be able to succinctly express the idea.	Requires some understanding of the realities of implementing a real project.	TBA
PC76	11:399-403	Finance	Investment decision	Unstated	Amount committed depends on risk perception and confidence.	If NPV is positive at discount rate, project is funded.		Engineers often express great frustration with investment decisions that affect them personally, and have limited if any understanding of what investors need to make good decisions.		
PC77	11:403-4	Finance	Engineering finance depends on value creation	Unstated	Engineering creates value by reducing the need for human effort and resource consumption, and also from improved predictability, reduced uncertainty, and often a part from technical ingenuity as well.	No awareness		There seems to be only a tenuous understanding of value creation among engineers and engineering professional organisations.		
PC78	11:404-9	Finance	Staged project decision making	Unstated	Projects are approved in stages as confidence increases	No awareness		While many engineers know that this is the kind of decision-making used by large companies, there is little understanding of the reasons for it.		
PC79	11:409-10	Finance	Engineering creates value by reducing uncertainty	Unstated	It is easier, usually, to add value to a project and increase the amount that investors are prepared to invest by reducing the perceived risks. Reducing perceived risks increases the project value and also the likelihood that a project will proceed. Careful and systematic checking also helps to keep projects on schedule with less stress.	Time spent on checking, reviews and inspections adds little if any value. It is essentially unproductive. Productive engineering has to involve innovation and cost reduction to add value.	Not mentioned (neither value from engineering, nor uncertainty, except in a statistical sense)	See uncertainty reduction measures as "admin", which is non-productive, of secondary importance	perceived irrelevance blocks learning	People in engineering, diversity, unpredicatbility, value from reducing uncertainty. Link investment risk to technical decisions: incorporate assessment of uncertainty into analysis.
PC80	12:419-23	Practice	All engineers negotiate	Unstated	Negotiation is part of the daily life for most engineers. Engineers negotiate on technical issues, commercial issues, salaries and work conditions, contracts and sustainability issues. Negotiation is the main conflict resolution process used in engineering.	No awareness		As noted before, few engineers learn to negotiate effectively.		Role playing exercises are the best way that I know for young engineers to learn negotiation skills, coupled with instructional material similar to that provided in Ch12. Samples available on request.
PC81	12:423-38	Sustainability	Sustainability in engineering practice	Unstated	Sustainability - notion that we are part of planet and planet (atmosphere) is part of us - closed system	Sustainable development is helping 3rd world or building solar power plants, not linked to community perceptions. "Politicians and CEOs set the direction, we just implement it."	Brundland definition (imply fixed definition), omit understanding of tacit knowledge and mental models in communication/pedagogy to understand hermeneutics	Replicate education message, miss ethical dimension, see as tick box requirement, superficial treatment, engineers decide model, disdain for "biassed" viewpoint, engenders community/stakeholder resentment and opposition, perception of common shared assets (earth, ocean, atmosphere) as "limitless sources/sinks" separate from us.	Language/thinking pattern inhibits perception of our connection with environment. Perception of other people (non-engineers) as illogical and biassed inhibits constructive interaction and ability to leverage community support.	1. Listening and perception skills 2. Language / listening skills 3. Identifying stakeholder understanding, interests, knowledge, language 4. Framing messages based on prior knowledge, interests, language 5. Negotiation skills
PC82	12:438-9	Ethics	Ethical behaviour supports effective engineering practice	Unstated	Ethics has a functional value as well as a moral one. Ethical behaviour supports referent power critical for effective coordination, and also reduces risks that stakeholder interests might be compromised through negligence (or intentionally), raising risks of external constraints being imposed.	Ethics has a moral value, possibly with links to legal liability in safety issues.	Functional aspects not addressed	Expert engineers instinctively understand functional as well as moral importance. While most engineers seem to behave with strong ethical values, few can see the practical reasons for ethical behaviour.	Explanations could help learning in acquiring effective reasoning capacity.	Negotiation role playing exercises can be helpful, particularly when young engineers have to take the role of marginalised groups, only to find themselves marginalised by their peers.
PC83	12:439-46	Values	Value frameworks help to explain how people think	Unstated	Value frameworks can help expose the way that people think in relation to future outcomes. For example, money-centred people focus just on money outcomes.	No awareness		Engineers mostly are unaware of these factors at an explicit level, though occasional remarks show there is some understanding at an intuitive level.		
PC84	12:446-8	Emotion	Human emotions influence engineering	Invisible	Emotional aspects of engineering include fear of unknown, lack of self-confidence, satisfaction at resolving a technical problem.	Irrelevant to practice, invisible, to be suppressed, unprofessional	No consideration of people	Emotional issues are considered difficult to handle, and are seldom recognised or even "permitted". "Good engineers leave emotions at the door." Understanding more about emotions could provide engineers with much greater capacity to learn positive interactions and engagement with people.	Invisibility of people (even the self) prevents effective learning of relevant skills.	Explain practice, distributed expertise, indirect value creation and reliance on other people. Restore people to central place in practice.

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PC85	13:470-88	Practice	Engineering is not the same everywhere	Unstated	Engineering relies on extensive technical collaboration that depends on social interactions and economics. Since social interactions and economics are strongly influenced by the prevailing social culture, engineering outcomes are also strongly influenced by the prevailing social culture. Compared with industrialised countries, a given engineering enterprise providing the same service quality can be much more expensive in equivalent currency terms.	Engineering is based on applied scientific principles that are universal. Engineering, therefore, is the same everywhere.		Most engineers, even ones who work in third world countries, don't stop to think about this. Engineers adopt a regionally based schedule of costs to help with estimating, and don't think much about the differences except in vague terms, such as "they don't take the initiative, and won't take responsibility" or "lack practical skills". Therefore, engineers have limited options for working through these issues and finding more reliable approaches that work consistently.		
X1	11:371	Finance	Money is a side-issue	Unstated	Engineers have difficulty understanding financial issues, accounting, while still appreciating its importance	Money is seen to be an issue for managers: engineers only deal with technical issues	Almost no mentions of topic	Most engineers have difficulty in understanding, appreciating, or explaining financial value.	Prior exposure inhibits ability to learn	TBA
X2	6:161; 4:95 (note 8)	Collaboration	Listening takes 20-25% of time	Unstated	Listening accounts for 20-25% of time for novice engineers	omission	Rarely taught: occasionally introduced for conflict resolution.	Inability to communicate, loss of accuracy in communication, loss of information content	We can all talk and hear, so what? Communication can't be taught. Idea of communication as one-way inhibits learning.	Research - significance, measurement of capacity. Incorporate instruction in listening in selected units. Avoid practices that reinforce perception that listening is not important (e.g. Providing comprehensive notes)