Insights into conceptual and contextual engineering problem-solving practices in the 21st century: some implications for curriculum redesign

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The poor throughput and retention rates in engineering education are of global concern. Engineering has become increasingly complex, particularly in the light of rapid technological development. The research presented in this paper contends that the theory/practice relationship is not adequately understood. In order to enable engineering graduates to effectively apply their knowledge and solve complex 21st century problems, it is necessary to develop a better understanding of what that problem-solving process entails. The research aim is to understand and map how different engineering practitioners work with different forms of disciplinary knowledge when solving industrial problems.

The research draws its theoretical framework from the field of the sociology of education, primarily the work of Basil Bernstein and Karl Maton, and the concepts of disciplinary knowledge structures and their impact on complex sociocultural practices. Using the Legitimation Code Theory (LCT) tool of Specialisation, the analytical focus is on the relationship between the significantly different forms of disciplinary knowledge in the multidisciplinary field of mechatronics engineering. Following a methodologically pluralist approach, data from 18 case studies in three types of industrial practice contexts have been collected in the form of participant texts, interviews and observations.

This paper presents three examples of problem-solving patterns that emerge following the application of a particular LCT instrument (the epistemic plane). The instrument enables a view of the problem-solving context as well as a 'map' of the problem-solving process. These 'maps' provide a useful framework against which to decipher disciplinary boundary crossing and 'code clashes' which may impede the problem-solving process. Understanding such code shifting and clashing may provide insights into the difficulties faced by engineering students and graduates when solving problems in increasingly complex contexts. It is also hoped that the findings will contribute to a view of curriculum that addresses the changing engineering practice landscape.

Introduction

"Advances in engineering have been central to human progress ever since the invention of the wheel" (UNESCO, 2010), and the role of the engineering practitioner in contributing towards socioeconomic development is crucial. In South Africa, engineering is cited as a particular area "in which skills are in short supply or decreasing" (CHE, 2009, p. 40). A report by the Human Sciences Research Council (HSRC) describes the current state in South African engineering "as one of the worst capacity and scarce skills crises in years" (Du Toit & Roodte, 2008, p. 1). The tertiary education sector responsible for producing engineering professionals is not managing to do so effectively enough, with low graduation rates and an average non-completion/dropout rate on engineering programmes of 50% (CHE, 2013; Fisher, 2011). However, this picture is not unique to South Africa. Local and international studies to determine the cause of low retention and high attrition reveal key factors are content overload, inadequate study skills, misconceptions about the nature of the engineering profession, and the disjuncture between science and engineering (Bernold et al., 2007; Vogt, 2008; Andersson et al., 2011). In a national comprehensive employer survey on graduate performance (Griesel & Parker, 2009), 56% of the industries surveyed were of SET (Science, Engineering and Technology) sectors.

The key gap to emerge is that "between employer expectations and higher education outcomes" with respect to application of knowledge (p. 1). It is this 'gap' that may be one of the reasons for the fact that despite the skills shortage, over 10 000 qualified SET technicians were recorded as unemployed in South Africa in 2012 (CHEC, 2013). In the Western Cape alone (the regional site of the research), 31.2% of all 2010 SET graduates were unemployed in 2012 (ibid.). Clearly something is amiss.

Engineering in the 21st century has become increasingly complex in the face of globalisation and exponential technological development. Tertiary education institutions, worldwide, face the unprecedented pressure of training masses of "professionals [equipped with the] broad problem-solving skills" (Kraak, 2000, p. 11) necessary to cope with the reality of an increasingly complex field. The demand "that graduates can deliver value from their first day in the workplace" (Case, 2011, p. 3) has resulted in widespread curriculum review and redesign processes. Selecting appropriate knowledge elements is complicated by the fact that "the 'content' of engineering practice other than basic principles is changing far too rapidly for engineering curricula to keep pace with" (Felder, 2012, p. 11). What exactly are the 'basic principles', though? The knowledge profile for all South African Higher Education engineering qualifications lists natural, mathematical and engineering science knowledge in one competency outcome, as though they were comparable (Engineering Standards Generating Body, 2012). This condensation suggests the lack of a "sophisticated understanding" (Shay, 2008, p. 596) of the nature and purpose of the disciplines in enabling engineering problem solving. The contention in this research is that we have a poorly informed conceptualisation of the nature of and relationship between both theory and practice with regard to enabling the 'problem-solving' abilities necessary for the different engineering qualification levels.

Based on a current PhD study, which is a continuation of earlier research into multidisciplinary engineering practice (Wolff & Luckett, 2013), the focus in this paper is primarily on an analysis of practices observed in three different types of industrial sites. It is the intention to better understand how successful novice practitioners draw on different forms of engineering disciplinary knowledge when solving a particular real-world problem. Using a set of theoretical tools and instruments from the sociology of education, notably the work of Basil Bernstein (2000) and Karl Maton (2014), the paper presents a 'language' through which to analyse engineering practitioner problem-solving practices. The early findings, based on 18 case studies, suggest there is a generative relationship between the nature of the problem solver, the problem environment and the disciplinary problem structure. Each of these elements may manifest a different orientation to both the 'what' and the 'how' of the problem. Where there are clashing orientations, a problem-solving process may be impeded. The paper begins with relevant elements of the theoretical framework and introduces one of the analytical tools. This is followed by an overview of aspects of the methodology, and the presentation of three sample case studies. The paper concludes with comments on the potential implications of the research and its attempt to make a contribution to developing an informed curriculum that will attract, retain and enable engineering graduates for a changing professional landscape.

Conceptual framework

Engineering is classified in Bernsteinian language as a 'region', which sees 'singulars' (pure disciplines such as physics and mathematics) combined into 'knowledge areas' appropriate to a specific occupational or professional purpose. The challenge with 'regions' is that they may lose sight of their disciplinary basis, and lack 'conceptual coherence' (Muller, 2008). The focus for this research is one of the most rapidly emerging and expanding engineering sectors – that of controlled electro-mechanical systems (or Mechatronics Engineering). Mechatronics represents one of many regions in which the growth of the region itself is not only directly related to but dependent on industry-generated technological developments aimed at more efficient automation or automated production. The reason for this particular focus is that the core disciplines that constitute the 'region' are significantly different: the mathematics and physics underpinning the mechanical and electrical elements, and what I am terming 'logic' as the discipline underpinning control systems and computer programming (Wolff & Luckett, 2013). Mechatronics curricula are broadly designed around three core subject areas: structures (mechanical engineering), power (electrical engineering) and control (computer and systems engineering). From a knowledge perspective, 'structures' and 'power' draw on the mathematics and physics underpinning mechanical and electrical engineering, albeit in different ways. 'Control', in this region, is based on the 'logic' and mathematics of computer engineering.

Knowledge structures and organising principles

The key Bernsteinian concept is that of the way in which knowledge is structured. Vertical discourse - formal "systematically principled" knowledge (Bernstein, 2000, p. 157) - consists of two primary structures which reflect the way in which knowledge has progressed in the field. Hierarchical knowledge structures, represented by the natural and physical sciences, attempt "to create very general propositions and theories, which integrate knowledge at lower levels" (p. 161). Hence, we see a 'subsumptive progression' of knowledge over time, where new theories or concepts extend and integrate earlier ones. Physics is the key hierarchical knowledge structure in Mechatronics engineering. Its organising principles are reflected in strongly sequenced concept chains. For example, Ohm's Law subsumes a number of concepts - the behaviour of electrons, the nature of different conductors, the principles of resistance and so on - and is reduced at its simplest to V=IR. The building of this kind of knowledge occurs over a long period of time, as is evident in the school's physics curriculum.

In contrast, horizontal knowledge structures "consist of a series of specialised languages with specialised modes of interrogation and criteria for the construction and circulation of texts" (Bernstein, 2000, p. 161). In other words, there are kinds of knowledge structures where the same type of knowledge has different 'languages'. Inherent in the notion of structure is the question of its strength (durability) and its relation to the world in which it exists. Young and Muller (2007) suggest that the difference between horizontal knowledge structures can be described in terms of 'grammaticality': "how theoretical statements deal with their empirical predicates" (p. 188). Those horizontal knowledge structures "whose languages have an explicit conceptual syntax capable of relatively precise empirical descriptions" (Bernstein, 2000, p. 163) exhibit 'strong' grammaticality. One such example is mathematics , the second key discipline in Mechatronics engineering. By way of example, the 'explicit conceptual syntax' in the theorem of Pythagoras (a2 + b2 = c2) clearly announces itself as mathematics, and stably identifies the relationship between the lengths of the sides of a right-angled triangle. Each of the languages in this kind of knowledge has strong and recognisable organising principles. Learning entails similar procedures to the learning of physics, for example. The difference is that there may be a different 'language' to draw on to represent the same knowledge. An algebraic linear equation, for example, can be represented using coordinate geometry, each with their own rules of syntax.

Then there are horizontal knowledge structures with 'weak' grammaticality, such as those of the social sciences, where the "capacity of a theory to stably identify empirical correlates" is weaker (Young & Muller, 2007, p. 188). The term 'functionalism', for example, is to be found in several disciplines, and would require clarification in particular contexts. Bernstein establishes that knowledge in such fields progresses by way of proliferation and redundancy. This is particularly evident in Information Communication Technologies (ICTs), a 'region' which is at the heart of 21st century computer-based engineering practice. This region represents the third key discipline: 'logic'. Evidence of the 'weak grammaticality' here lies in the use of common words, such as 'function' or 'object' which take on specific meanings in different programming paradigms. Working with these knowledge structures requires one to constantly refresh one's knowledge base, adapt to new forms, and respond to a different set of organising principles. This implies "masses of particulars" (Muller, 2008, p. 15) need to be learnt independently, not necessarily sequentially as in the case of physics, and more often than not in specific and multiple contexts. So, the question for this research is what happens when these three significantly different disciplinary structures meet in a problem-solving moment?

Legitimation Code Theory

Legitimation Code Theory (LCT) forms a core part of a broad social realist 'coalition' of approaches which reveal knowledge as both socially produced and 'real', in the sense of having effects. LCT provides a rich (and developing) "sociological toolkit for the study of practice" (Maton, 2013, p. 5). One dimension of the 'toolkit' is the concept of Specialization which "extends and integrates Bernstein's concepts of 'grammars'" (Maton, 2014, p. 95). Specialization is about 'what counts'. What is legitimate in a field of practice? There are two sets of specialization relations: those concerned with knowledge and those concerned with knowers. The former provides one of the frameworks for the data presented in this paper. The 'relations' concerned with knowledge are called 'epistemic relations' (ER). ER "highlights that practices may be specialized by both what they relate to and how they so relate" (Maton, 2014, p. 175). In other words, practices are recognised as legitimate by participants in the field of practice. The relationship between 'what' the practice relates to and 'how' it relates is illustrated on a Cartesian plane (Figure 1). The y axis (vertical) represents the strength of the relationship between a knowledge claim and the empirical data (ontic relations), in other words what is the focus of the claim. The x axis (discursive relations) represents the strength of the relationship between ways of referring to or dealing with (how) a particular object of study (the empirical data). This gives us four quadrants which each represent a different insight.

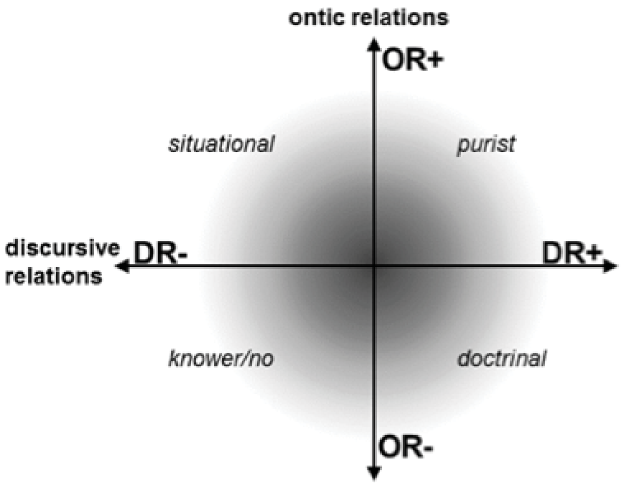


Figure 1. The epistemic plane (Maton, 2014, p. 177)

The following are examples of engineering knowledge practices which illustrate the four insights:

Purist insight: Here we see strong adherence to both the phenomenon studied and the approach. The concept of structural 'force' in physics is governed by a commonly agreed set of laws and expressed in particular formulas, which thus dictate particular procedures for determining force at a given moment in a system. In other words, there are both strong ontic relations (OR+) – what - as well as discursive relations (DR+) – how.

Doctrinal insight: This is the notion of practice governed by methodological dogmatism, and very common in the way in which students/graduates have been taught to apply mathematics. Mathematical models and methods are followed rigorously, implying stronger discursive relations (DR+) irrespective of the phenomenon (OR-). Similarly, a dogmatic methodological approach to a problem or process also sees practices based on doctrinal insight, where the method is more important than the phenomenon in question.

Situational insight: "Knowledge practices are… specialized by their problem-situations" (Maton, 2014, p. 176), which means a greater degree of methodological freedom (DR-). In other words, there are more ways to accomplish the same thing. Any number of programming languages or technologies, for example, can be used to fulfill the same objective. Businesses which specialise in custom-made machines display a situational insight orientation as the particular customer needs could be met in a number of ways. The focus of the potential solution is strongly bound (OR+) by a particular need (what), but the means to accomplish this (how) may vary (DR-).

Knower/no insight: This is the weakest point of the epistemic relations, either characterised by an 'anything goes' (OR-,DR-) philosophy or the practice is legitimated through the "attributes of the subject" (ibid.), in other words, a knower code. This insight is dominant when a decision is based on the nature of stakeholders and not a particular phenomenon or method.

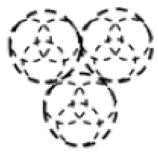
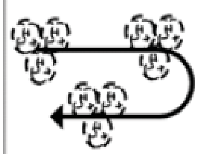
The two key concepts of *knowledge structures and epistemic relations* are used in this paper to analyse mechatronics engineering practice. Each knowledge structure and each insight represents a kind of 'code', a way of thinking. Each 'code' or 'insight' is significantly different. In a multidisciplinary field it is quite conceivable that one needs to shift one's way of thinking at different times. The question in this research is what does this shifting look like in different but comparable engineering problem-solving contexts?

Methodology

The research seeks to understand how mechatronics practitioners in a range of industrial sites solve problems in the context of a controlled electro-mechanical system. The contention is that in the problem-solving moment, the engineering practitioner needs to navigate his/her way through different disciplines, which have different organising principles and require different ways of thinking. This 'navigation' entails not only crossing disciplinary boundaries, but dealing with knowledge code clashes. But this is not the only thing a practitioner has to navigate. There is an entire contextual world around the machine or system in which the technical problem occurs. A key concept to assist in understanding this complexity is Herbert Simon's (1996) distinction between the inner and outer environments of a particular 'artefact'. The 'artefact' here is the focus of the engineering problem itself – the actual technical problem site. The inner and outer environments of the problem site may differ significantly enough to impact on the problem-solving process. "The inner system is an organisation of natural phenomena capable of attaining goals in some range of [outer] environments", which, in turn, "determine the conditions for goal attainment" (Simon, 1996, p. 11).

Three inner/outer systems contexts have been classified: the Contained Systems environment, where the focus is a discrete 'contained' object that fulfils a particular stand-alone function; the Modular Systems environment where different machines and subsystems are built or set in relation to each other to form an automated system; and the Distributed Systems environment - such as manufacturing - where the focus is on actual production. While the 'inner' environment of the problem itself may be the same in all these contexts, the 'outer' environments differ significantly with respect to scale, stakeholder relations, procedures, and organisational structures. The categories are illustrated in Table 1, and are based on the nature of the range of industrial sites where participating mechatronics technicians and technologists in the Western Cape are employed.

Table 1. Mechatronics systems categories

System	Representation	Examples	Industries
A **Contained**		• Microwave oven • Automated medical device • Vending machine • Access control system	• Tech R&D • Prototyping • Component suppliers
B **Modular** *(sets of contained-type systems)*		• Production machine • Production sub-system	• Machine Builders • Machine Suppliers • Systems Integrators • Panel Builders
C **Distributed** *(sets of modular systems)*		• Production line • Manufacturing plant • Factory	• Manufacturing • Packaging • Food & beverage processing

Data collection proceeded in three phases beginning with a questionnaire requesting a description of the context, the most recent technical problem faced, and how the practitioner solved the problem. The volunteer participants, barring one, all hail from the same institution, and are regarded as 'novice' practitioners with between one to five years' industrial experience. 27 questionnaire responses were sifted for appropriacy and then allocated to a specific category. 18 were selected for phase two: a semi-structured re-enactment interview recorded in both audio and video formats. The re-enactment protocol entailed the practitioner's 'reliving' the problem moment and context by using the actual artefacts in their original problem location (where possible).

The problem-solving process was divided into three stages:

- 'how' the practitioners approach the overall problem itself
- 'how' they determine the cause (analysis)
- 'how' they implement a solution (synthesis)

This process was mapped onto the epistemic plane (Figure 1) to capture the problem-solving trajectory across different insights – in other words, the 'basis' of their thinking and action at each of the three stages. At the heart of each problem lies a particular configuration of mathematical (red), physics (green) and logic-based (blue) knowledge within a particular context (purple). These knowledge areas were colour-coded on the problem-solving maps so as to enable a visual depiction of both the knowledge type (with its relevant structural characteristics) as well as the dominant insight at a particular stage of the problem-solving process.

The third phase entailed industry expert verification of the analysis. In order to enable the industry experts to understand the analysis, the epistemic plane was simplified using accessible terminology and translated into the '5P' model (Figure 2).

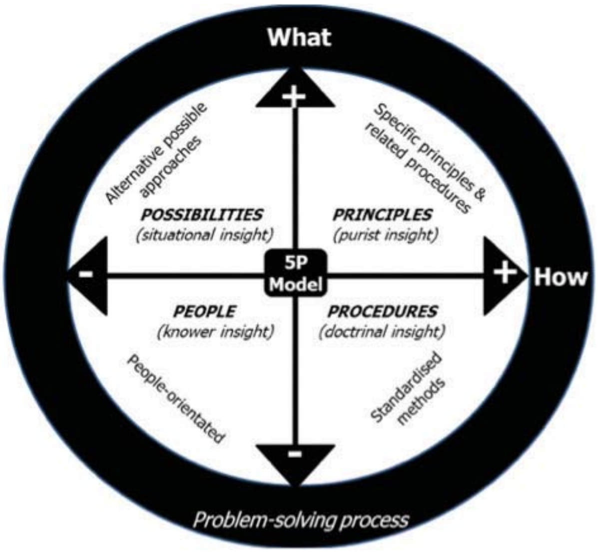


Figure 2. . The '5P' problem-solving model

Although the '5P' model loses some of the nuances implied in the epistemic plane, it was used as a simple translation device to enable experts to talk about how the participants engaged with their particular problems. The lower left quadrant ignored the 'no' insight element and retained the 'knower' orientation, as it had emerged as being significant across all the case studies. For the purpose of the PhD study, the expert verification discussions were translated back onto the epistemic plane and interpreted using the ontic relations and discursive relations discourses. For the purpose of this paper, I will continue to use the 5P model, but will refer to the insights as per the formal LCT names.

Problem-solving case studies

Three case studies have been selected for this paper, one drawn from each of the contextual categories. Each case study will be briefly introduced, but the focus for this paper is on the element of 'code shifting' or 'code clashing'. In each case, a possible implication for curriculum is suggested.

Case study A1: contained systems

Technician A1 has worked in a small separate R&D unit at an access control systems manufacturer for 18 months. A new automated access control system is being developed by the company using a more powerful microcontroller. A1's role is to add a 'battery disconnect circuit' (amongst other things) to the new system. He built a prototype circuit using what is called a 'Zener diode' to read the voltage levels and trigger the disconnection and reconnection of the battery. However, when he transferred the circuit to the actual PCB (printed circuit board), he had not taken the capacitance into account, and the current surge blew the transistor. A1 needed to regulate the incoming energy better, and solved the problem by adding a different component - a P-channel Field Effect Transistor (FET).

The dominant insight orientation in this part of the business is 'situational/purist' - these access control systems are custom-made designs – in other words responding to a particular customer 'situation', but also based on the appropriate laws of physics underpinning electronics. There are different possible solutions to a specific technical need, but each solution is underpinned by specific principles, the key one in this case being Ohm's Law.

A1 displays a typical situational insight in all aspects of his life and work. He loves trial and error experimentation, is haphazard in his approach to problem-solving, and relies on previous experience:

> 'I tend to refer to a lot of older designs - I have a whole bunch - and if I need to reference something I go there, but if it's something new I would do a quick google search' (A1).

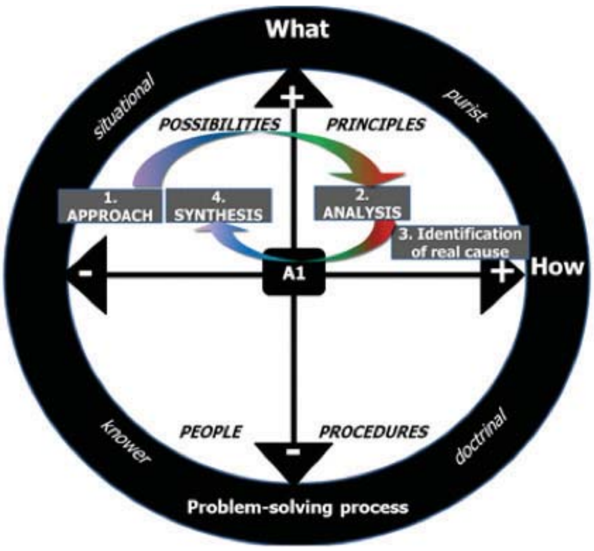


Figure 3. . A1 problem-solving process

The problem-solving trajectory is illustrated in Figure 3. He approaches the problem (1) from a situational perspective. In other words, here is a new product and it needs to do a number of additional and different things from the one previously produced, and there could be a number of ways to do this: the first solution attempted being the Zener diode circuit, and the second (following the impact on the transistor) being the P-channel FET. He is required to shift into purist mode when analysing (2) the cause of the blown transistor. There is not necessarily a logical or procedurally efficient sequence to his explanation. He moves from one circuit to another and then to a different component, but at each stage explaining the various power values (**mathematics**). He articulates the various aspects of Ohm's Law (physics) continuously, several times also correcting himself. He determined that the difference between the PCB and the prototype was the existence of the capacitors (3) and that he needed to regulate the voltage better. He consulted Google, having used FETs before and suspected they might work. He deduced from the component explanations on a particular website what he should do. In other words, he 'synthesised' (4) a solution for this particular problem in this context by implementing one of a number of solutions, which had to fit into the logic of the PCB as a whole.

The problem in this case study is precisely that of the research: the implications of the broader/wider context. When A1 moves his prototype design to the actual circuit board environment, he has not considered all the other components on the board, how they are connected and how the energy flow through all the components might affect individual components. The movement between situational and purist insights is appropriate in this context, as the two insights represent both a typical R&D environment and the nature of the problem. However, as a practitioner, he confesses that he "basically came here knowing nothing" and that his conceptual grasp of the disciplinary basis of the problem was lacking. The shift into purist mode represents a code clash for A1 as a practitioner. However, as is the nature in the sector, A1 is part of a small team. His colleague (another participant in the research) is a clear purist, preferring well-established and known principles and related procedures. The colleague admits he gets "frustrated when this language can't do what another language could do, because I always used that feature and then I have to find a way around that" (A2). The synergy between different members of the small R&D team - with different insight orientations and open lines of communication - facilitates effective problem-solving in this context. A key feature, therefore, of successful problem-solving practice in such contexts is access to the collective 'reservoir' (Bernstein, 2000) of available knowledge and supportive stakeholder relations. It is this aspect of supervised 'team work' that the engineering curriculum tries to emulate in the provision of project opportunities. All too often, however, the structure of the project teams is not necessarily taken into account, and the expectation is that all members are equally equipped in all areas.

Case study B2: modular systems

B2 works as a machine builder and systems integrator (3 years), moving from one manufacturing site to another to maintain and improve existing production processes where his company's custom-made machines have been installed. The company also oversees an international machine builder's local clients. B2's dominant purist insight orientation reveals itself in his systematic, detailed and analytical questionnaire response. Although he is a purist in nature, his customer environments are doctrinal procedures-driven manufacturing plants. B2's standard approach is thus necessarily from a situational perspective (1), as each context is different. This is followed with a detailed analysis of the context (2a), the existing and required processes (2b), the human decisions (2c) in relation to those processes, and finally an analysis of the problem-site artefact (2d). The large company in question manufactures pharmaceutical products. One of the internationally-supplied packaging production lines entailed two sealing bars above and below the product. The two bars were not completing the packaging cycle at the same time. The fault was registering as an overload on the top servo motor. After establishing this context, technician B2 studied the production process in 'inching mode':

> 'I noticed that the bottom bar had finished its motion while the top one was still in motion and pushing the bottom bar. That was clearly the cause of the overload' (B2).

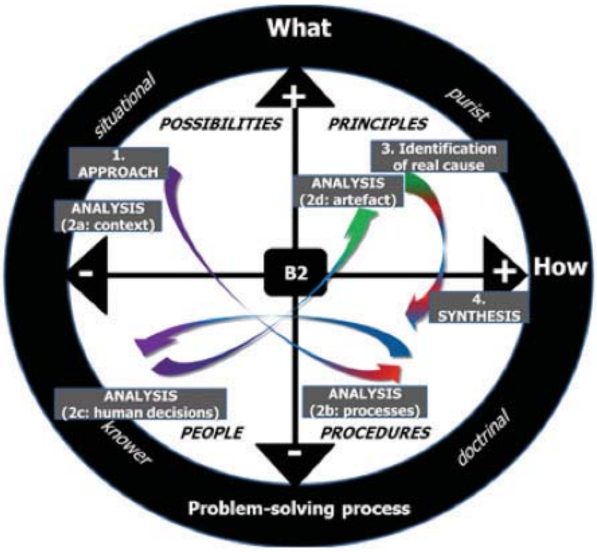


Figure 4. B2 problem-solving process

B2 then investigated the possible impact of any recent changes to the system. It was revealed that through a maintenance process the top sealing bar had been replaced, and that the new bar measured under a millimetre thicker than the old bar – sufficient to cause a difference in the high-speed motion of the production line. The synthesis of a solution (4) entailed the procedural modification of parameters on the control system to allow both bars to complete the cycle simultaneously.

The interesting feature in this case is the fact that the company had already attempted to solve the problem by consulting the international suppliers (remotely). They had been advised to replace the motor, then the drive and the cable. None of this had solved the problem. The local company did not think to mention the sealing bar had been replaced, and did not realise it was slightly thicker. The international suppliers did not enquire about any changes to the system. B2 explained the difference the fraction of a millimetre made to the process, drawing on the physics and mathematics of force, motion and friction.

The problem-solving trajectory through different insights reveals a kind of analytical process that could be equated with purist thinking. For this practitioner, each of the contextual and conceptual elements entail distinct principles and associated procedures. His grasp of the requirements of the different insights is reflected in his appropriate use of different discourses at different stages of the explanation, and this case study reveals no evident code clash. This is one example of four full-cycle cases where the practitioners all happen to be high achievers in both mathematics and the logic-based subjects. Such cases represent only 2.9% of a total of 290 under-graduates on the mechatronics qualification in question. I will make no generalisable claims here about the correlation between ease of movement across insights and the high achievement in both mathematics and logic programming. I would like to suggest, however, that the nature of the two types of horizontal knowledge structures (strong and weak 'grammaticality') are reflected in the difference between strong and weak discursive relations (the x axis on the epistemic plane) – in other words, the movement between fixed, commonly agreed procedures and a range of possible procedures. It is crossing this boundary from right to left or left to right that has emerged as presenting the most common of code-shifting challenges, if not explicit code clashes, across the majority of case studies in this research. The implications of the relationship between knowledge structures with strong procedures and those with open-ended or choice-based procedures are significant for curriculum rethinking, as these subjects are often treated as separate.

Case study C1: distributed systems

Technician C1 has worked at the medium-sized automotive component manufacturer for four years. He is responsible for monitoring, improving and reporting on specific production line processes. The company has a distinct doctrinal orientation and is run according to a strict 6 sigma methodology, which is "a disciplined, data-driven approach and methodology for eliminating defects" (www.isixsigma.com). The focal problem is relatively straightforward. A production line is rejecting components due to their ostensibly not meeting the product height specifications. Visible inspection of the rejected parts suggests they cannot all be defective. It seems clear that the height-measuring device itself is problematic. This is a sub-system (mounted on the production line) consisting of 'linear probes', which 'touch' the product and send a signal to the computer to verify whether or not the height is accurate.

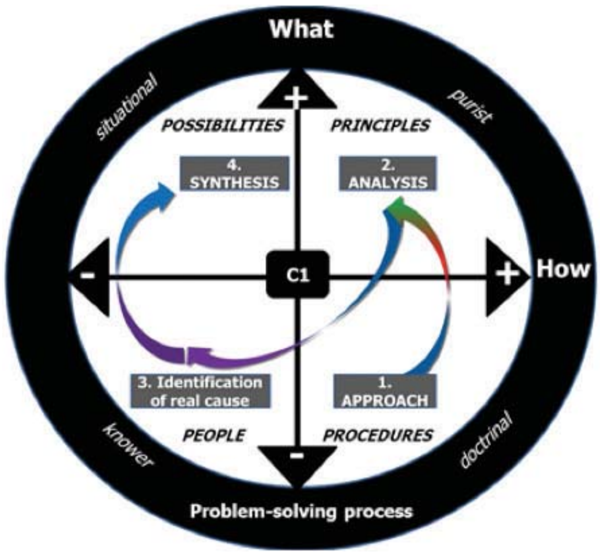


Figure 5. C1 problem-solving process

C1 approaches (1) the problem with a doctrinal 6σ methodology and describes the definition, measurement, analysis (2), and implementation of a solution (4). Through his root-cause-analysis methodology on the physical artefact itself, it is determined that an inappropriate 'connector bank' has been supplied by European manufacturers (3). The connector bank is used to reduce unnecessary cabling, and the one in question is intended for digital inputs. It has built in Light Emitting Diodes (LEDs) which cause voltage interference in the highly sensitive analogue probes, and thus cause the height measuring device to reject components as it is not getting a 'clean' signal. The entire analysis is from a purist perspective. The interim solution (situational) is to bypass the connector bank and wire all the linear probe cables directly into the PLC (which is not ideal as it causes various delays and slows down overall production processes).

C1 is not naturally of either purist or doctrinal orientation. He is essentially a situational problem-solver, preferring trial and error and drawing mostly on experiential knowledge. However, he has absorbed the company's strict methodology, and according to his supervisor his process is "structured and well-sequenced if he understands the machine... when he does not know something, he jumps around quite a bit".

The problem took three days to solve, and entailed the step by step alteration of every component between the probes and the PLC, as per the standard approach in this context. Although the industry expert was quick to defend this process, he conceded that they had neglected to check the connector bank properly – the changing luminosity on the visible LEDs should have been a clue to voltage interference on the highly sensitive probes. In other words, if C1 had taken a moment to absorb the problem in context (and taken the suppliers into account by reviewing their documentation), he may have solved it far more efficiently. However, given that the supplier is a highly reputable one, C1 admitted he "assumed it was meant to be like that... European machine suppliers think they're of a high standard". The cause of the problem was human error and required an unsatisfactory situational solution.

C1's problem-solving trajectory is a common one in this research, and his doctrinal approach is standard in the 'Distributed Systems' category. In most of these cases it emerges that a supplier or stakeholder is responsible for a decision that leads to an error. In each of the similar cases, the participant has assumptions about the reliability of new components and equipment, and neglects to take the contextual stakeholders (or their documentation) into account. Secondly, when dealing with international stakeholders it emerges that few of the participants have the requisite ability to comfortably shift to a knower insight orientation – in other words, they do not necessarily know how to engage productively with stakeholders who literally speak a different language and follow different procedures. While our curricular attempts to include 'communication skills' courses are intended to enable improved communications, these courses do not necessarily capture the range of discourses and ways of thinking that an engineering practitioner is going to encounter in an increasingly global context.

Concluding comments

This paper has presented three case studies to demonstrate engineering technician problem-solving practices in three different contextual categories. Using tools drawn from the sociology of education, namely the Bernsteinian concepts of knowledge structures and the LCT dimension of Specialization, the analysis entailed the graphic plotting of actual problem-solving trajectories, highlighting the shifting between significantly different forms of and approaches to disciplinary knowledge.

A key finding to emerge is that the most common code-clash or code-shifting challenge is along the horizontal axis, between stronger and weaker discursive relations. In other words, the shift between fixed ways of doing things and a broader range of possibilities. From a disciplinary perspective, mathematics and logic respectively represent the knowledge forms on either side of the 'discursive relations' continuum. Across all the case studies - barring the four anomalies (including B2) - the practitioners manifest an insight orientation on one particular side, and this happens to be reflected in their academic performance profiles as a significant difference between mathematics and the logic-based subjects. This suggests the practitioners are orientated towards certain disciplinary ways of thinking. In supportive, possibly smaller environments - such as in the case of A1 - the navigation of disciplinary boundaries (or code-shifting) is facilitated through access to a collective 'reservoir' of knowledge. A second finding to emerge is that the larger the scale of the environment, the more doctrinal its key orientation is likely to be, and the greater the chance is that a situational practitioner will experience a code clash. In three such cases, the participating technicians have subsequently left their companies. They were simply not suited to the environment.

The evidence of 'code shifts' and 'code clashes' in different contexts suggests that the engineering curriculum could benefit, first of all from an analysis of the different forms of code in the different knowledge areas, and secondly, by making such differences explicit, particularly in cases where code-shifting is anticipated. Furthermore, there is a clear need to introduce curricular elements that entail weaker discursive relations – in other words, problem contexts that offer a range of possible approaches, particularly with respect to both technology and knowers. It is hoped that this research will contribute to an engineering educational experience better suited to the rapidly changing landscape of 21st century engineering practice.

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