Closing the loop in engineering educator development:

Using theoretical and empirical research to inform curriculum and teaching

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Abstract—**The challenge for engineering educators remains the ability to enable their students to bridge the seeming divide between disciplinary fundamentals and practical application. With a significant percentage of employers stating that graduates lack the required technical skills in the 21st century workplace and the rapid proliferation of technologies, educators cannot hope to prepare their students for all possible scenarios. One way to overcome the potential burden on the engineering curriculum is to enable engineering educators to develop a more conceptual understanding of the relationship between theory, practice and technology. This paper presents case studies of professional development work with academics in a range of engineering disciplines, where feedback from the field of engineering practice and empirical educational research has assisted in enabling improved curriculum redesign, teaching and integration of learning technologies. Drawing on theoretical tools from the Sociology of Education, the research project used to support engineering academic development entailed a series of problem-solving 'maps' which reveal how solving a technology-based engineering problem requires the ability to 'code-shift' between the different engineering disciplines. Taking research of this nature back to educators adds a missing dimension in the development of engineering pedagogical competence.**

Keywords— Engineering problem solving; Legitimation Code Theory; academic development; curriculum design; code-shifting

I. Introduction

An emerging challenge in engineering education is the rapid proliferation of increasingly complex technologies and contexts of socio-technical application. Unless actively involved in applied engineering research and industry collaboration, academics run the risk of remaining trapped in the traditional paradigm [1] and out of touch with the complex realities of 21st century technology-based engineering practices [2]. The consequences of this disjuncture are evident in numerous global surveys highlighting graduate deficiencies in the required technical skills [3]. In response, we see several progressive initiatives to shift instruction towards problem-based and active learning, as well as the integration of technology enhanced instruction methods and platforms.

However, despite the ostensible affordances of technologies for learning, the dynamic evolution of technologies in general places significant pressure on engineering educators. A key challenge remains the identification and selection of appropriate learning opportunities and platforms that will both enhance the students' *conceptual understanding* as well as the ability to effectively engage at a *practical level* with engineering technologies in different workplace contexts. Such decisions start with an understanding of pedagogy and disciplinary content as well as technological knowledge as defined by the TPACK [4] [5] framework.

An overarching principle in education is the notion of constructive alignment [6], where explicit learning-focused objectives govern what educators select, how they teach this and create appropriate opportunities for the intended learning, and then enable students to determine their progress through assessment. In other words, constructive alignment is about the coherence of a system. This paper suggests that a missing element in the alignment framework is what happens outside the educational system. Who are our students and how do they learn? Where do our graduates go? What industrial developments are emerging? What role do the various internal and external stakeholders play in shaping our curricular decisions? These are but a few factors that impact on the engineering education system and the decisions regarding what we teach and how we enable learning. If we are to aim for holistic constructive alignment, we need to regard the system as dynamic with multiple inputs, outputs and variables. I suggest that one valuable resource for engineering educators is knowledge of educational research from the field of engineering practice.

A plethora of initiatives is presented annually at various Science, Technology, Engineering and Mathematics (STEM) education conferences, as well as a range of methodologies frequently promoted as bases on which to design teaching approaches. Many of these remain 'victory narratives' or 'show-and-tell' that are contextually bound. The argument in this paper is firstly that a more conceptual understanding of how different kinds of engineering knowledge and practices work can help lecturers to make informed curriculum, teaching, learning and assessment decisions. Secondly, with much of the recent focus on student-centred learning, educators have begun to acknowledge the importance of understanding the student base, matters of diversity, context and differentially equipped students. This understanding may enable a 'feedforward approach' in planning pedagogical initiatives [7]. However, I argue that a synergistic 'feedback approach' is necessary, not just with respect to student feedback during a course, but from the eventual site of practice – industry.

Drawing on previous (published) research on graduate engineering problem-solving practice in industry [8] [9] [10], this paper is based on a post-doctoral research initiative to assist in engineering educator professional development. Using a range of theoretically-informed, empirical problem-solving case studies from industrial sites, a number of staff workshops have been conducted to 'close the loop' between educational theory and engineering practice. The paper outlines the original research (presented in detail at EDUCON 2017) [8], and elaborates on the theoretical tools and case study findings in the context of engineering educator development.

II. Research context

In an effort to address urgent scarce engineering skills shortages in an emerging economy (South Africa, the focus of this research), a number of international collaborative professional development initiatives are underway to enhance existing engineering educator capacity. As a member of two of these research teams, I have used the opportunity to integrate the findings of my post-doctoral research in two university engineering faculties – a traditional research-intensive university and a University of Technology.

The post-doctoral research project (which extends the original PhD study on mechatronics engineering across sectors) examines the relationship between different kinds of engineering knowledge and practice by mapping the problem-solving strategies of engineering practitioners in industrial sites. The collective research has generated problem-solving maps across over 40 case studies using an analytical tool drawn from Legitimation Code Theory (LCT) [11]. The LCT *epistemic plane* enables the visualization of different ways of thinking across the approach, analysis and synthesis stages of solving engineering problems involving control technologies at industrial sites. One of the key findings is that successfully navigating an engineering problem requires the recognition and realization of the different disciplinary rules, and an ability to *code-shift* between the different ways of thinking in particular contexts.

This paper takes this educational research on engineering practices back to engineering educators. The research findings and affordances of the analytical tool have been integrated into two series of engineering educator development initiatives at two different engineering faculties. The intention of this 'feedback approach' is to highlight the importance of empirical theory-practice research so as to enable educators to explicitly integrate disciplinary 'code-shifting' opportunities into their engineering curricula and teaching.

A. Research Site & Participants

Two groups of South African engineering educators have been selected for this paper. They form part of a larger collaborative project on enhancing existing engineering educator staff capacity (known as the EEESCEPT project). Group A (10) are mainly process engineering academics at a traditional university who are engaged in efforts to improve the teaching of particular subjects in a four-year chemical engineering Bachelor's degree. Group B (18) is an entire department teaching industrial engineering at a University of Technology, and who are redesigning the three-year Diploma curriculum as a result of changes in the national qualification system.

B. Research Methods

This paper focuses on the use of methods and findings from engineering problem-solving research in service of engineering educator academic (or professional) development. This is one of the deliverables of the post-doctoral research project. A great deal of data on engineering theory-practice relations has been gathered over the course of seven years. The methodologically pluralist problem-solving case studies draw on surveys, semi-structured video interviews, as well as participant and company profiles [12]. For this paper, additional use has been made of facilitator observation notes, lecturer discussions and annotated graphic analyses texts produced during formal staff development workshops at the two different university sites during the course of 2017.

III. Theoretical framework

The overarching theoretical framework is based on a social realist view that knowledge is not only socially constructed, 'but also real in the sense of possessing properties, powers and tendencies that have effects' [11]. The social realist, Basil Bernstein [13], developed a 'code' theory which highlighted key differences between forms of educational knowledge based on how such knowledge emerged from the field of production. He argued for the recognition of these differences as a way to empower both educators and students to better grasp how knowledge works. Engineers and educators might intuitively recognise that the mathematics and natural science in a traditional engineering curriculum require very specific ways of working with knowledge, and that these ways differ significantly from those required when using different forms of technology, which are based on the discipline of 'logic'. The challenge is to enable practitioners to move beyond intuition and to develop a more informed perspective on the nature of knowledge.

Legitimation Code Theory (LCT) extends the early work of social realists in presenting a range of dimensions which can aid researchers to 'see' and understand what exactly happens when human beings engage with 'knowledge practices'. LCT helps to make 'organizing principles' explicit [11] and has been used extensively in research across the educational spectrum, particularly in chemistry [14], biology [15], design [16], engineering design [17] and chemical engineering [18]. One useful analytical tool from the LCT dimension of *Specialization* is the concept of *epistemic relations.* This is demonstrated through the use of the *epistemic plane* [11]*,* which focuses on the knowledge components of any practice.

Represented as a Cartesian plane (figure 1), this is a graphic way of representing the relationship between a phenomenon (what) and its approaches (how) in any particular knowledge practice. The vertical axis describes the *ontic relations* (the strength of the identity of the 'what'), whereas the horizontal axis describes the *discursive relations* (how strongly the approach to the phenomenon is bounded – the 'how'). The two axes of strong/weak continua give us four ways of seeing knowledge practices – four *insights*.

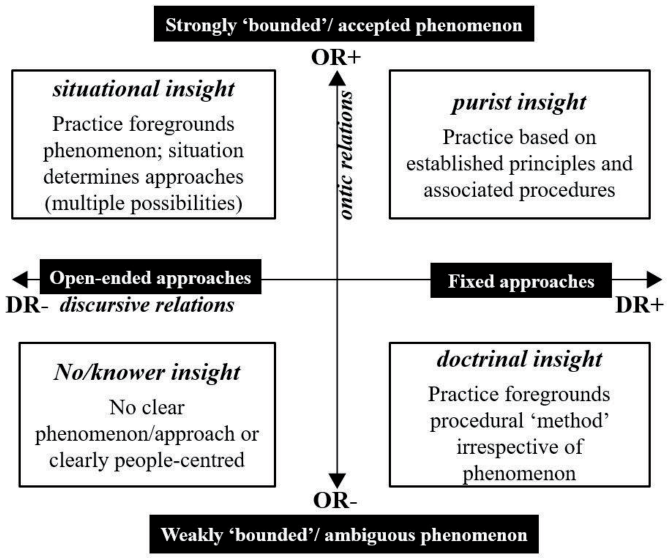

Fig. 1. Modified and annotated epistemic plane [11]

The strongest quadrant *(purist insight*) sees an unambiguous 'what' and 'how' in that the phenomenon being addressed is commonly accepted and has standardised protocols. The weakest quadrant sees an ill-defined or ambiguous phenomenon with open-ended approaches, which implies either *no insight* or the fact that the practice being observed is not about knowledge, but 'knowers' (hence the label *knower insight*). The alternate quadrants represent either strongly bounded phenomena with multiple approaches (*situational insight*) or strongly bounded procedures that could apply to any phenomenon (*doctrinal insight*).

In this paper, the *epistemic plane* is used for two purposes: 1) to summarise research findings on engineering problem-solving patterns at industrial sites, and 2) to demonstrate how these findings and the analytical tool enable engineering academics to approach curriculum design as well as teaching, learning and assessment of technology-based engineering subjects.

The following are practical examples of the significance of the *epistemic plane* for engineering educators:

- The *purist* quadrant represents concepts and approaches that are regarded as accepted by the field – to a large extent these are the fundamentals of the natural sciences. Most Higher Education textbooks – irrespective of context – would include Newton's laws of motion, Ohm's law, the laws of thermodynamics, and so on.
- The bottom-right (*doctrinal insight*) quadrant sees the teaching of standardised methods, such as the Scientific Method, syntax rules in programming, and differentiation/integration rules in Calculus.
- The top-left *(situational insight)* quadrant is where the phenomenon being addressed is quite clear, but there are multiple factors determined by the situation which can mean a range of approaches, such as deciding which control system or programming language to use.
- The bottom-left quadrant has both a weakly defined or contested phenomenon and no clear approaches (*no insight*). Alternatively, in this 'knowledge-weak' quadrant, what we find is that the practice itself is determined by conditions in the stakeholder environment, and practices are thus dependent on *knower insight*, such as selecting software or hardware based on brand awareness and familiarity, or designing learning opportunities to develop team work and self-regulated learning.

Each of these *insights* on the *epistemic plane* is a form of code. The kind of deductive, analytical thinking around a physics-based problem is different from the procedural rigor of programming, for example. Each of the disciplines and academic or industrial contexts have different discourse conventions. Recognizing how each code works and shifting from one code to another lies at the heart of effective problem solving. This is not to suggest that each discipline only 'belongs to' a particular *insight,* rather that we can use the plane as a whole in multiple ways to enable students to understand how the different 'codes' work even within a single discipline. For example, teaching a student thermodynamics requires a *purist* grasp of a number of verbally stated principles, a *doctrinal* grasp of the governing equations, and a *situational* grasp of the multiple possibilities in a given thermodynamic system. Enabling students to code-shift through these different *insights* ultimately reinforces their grasp of a particular disciplinary concept and their recognition of its *insight* home-base.

IV. ENGINEERING PROBLEM-SOLVING STUDIES

The PhD and post-doctoral research projects saw the analysis of the problem-solving practices of technicians, technologists and engineers across micro to large engineering businesses. Using the *epistemic plane*, the problem-solving trajectories were graphically mapped based on how these practitioners approached a problem, analyzed the cause and implemented a solution (see example in figure 2). Simultaneously, the problem-solving maps captured which of three key disciplines the practitioners were drawing on (whether implicitly or explicitly) at any stage in the problem-solving process: physics (green), mathematics (red) and logic (blue). [Other forms of knowledge regarding context were represented in purple.]

The example given in figure 2 is that of a technologist required to develop an affordable prototype system to measure temperature changes and gather the data on a computer. He set up a demonstration kit using the cheapest feasible and available components, including a breakout board with input sensors (temperature) amongst other electronics components, and output wires to an analogue/digital measurement device. All the information is sent to a computer on which a program is installed to engage with the data. Having populated the breakout board and connected it to the digital/analogue device, he still received no signal on the PC. During the video-recorded, re-enactment interview (where the participant describes the problem-solving process retrospectively), the technologist explained:

"Within minutes I smelt that tell-tale electronic burning smell. Straightaway, I unplugged the USB from the computer – removing the power was the first step to prevent further damage".

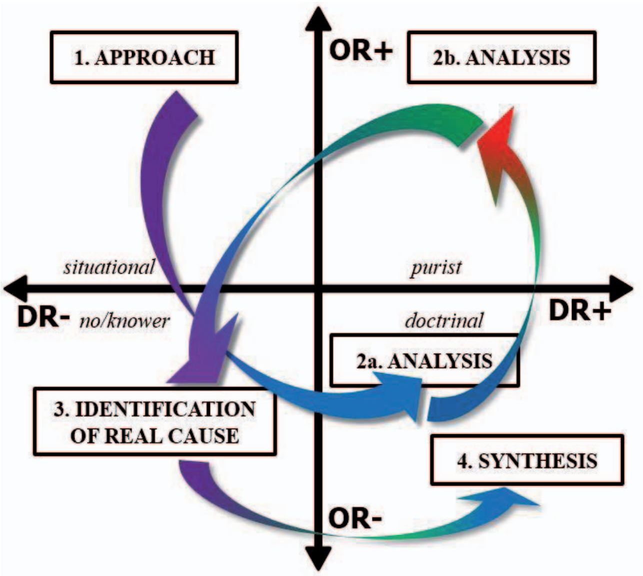

Fig. 2. Problem-solving strategy of an R&D mechatronics technologist

He suspected he had misconnected a component called an Op-Amp, because "*the pin configuration on the manufacturer's datasheet was incorrect on the version that was available on the supplier website*". However, following investigation, he discovered it was the incorrect configuration on yet another component – a temperature sensor built into a small integrated circuit (IC). He had inadvertently connected power to the ground terminal and ground to the power terminal, which had caused the IC to 'blow'. He replaced the IC, connected the pins correctly, and the system functioned as required.

Captured as a problem-solving map, we see a *situational* approach (he could have tried a number of things initially), to a procedural step-by-step removal and testing of each individual aspect of the system (*doctrinal*), to the analysis and understanding of the pin configuration (*purist*) – which had been altered from previous versions of the supplier documentation (*knower*), and which when corrected follows yet again a procedural set up.

Comparing case study data from different categories using the *epistemic plane* analyses, a number of significant disciplinary patterns emerged in the research findings:

- As a general rule, the engineering participants referred to physics concepts in *purist* or *situational* terms, such as trying to regulate voltage using Ohm's Law or investigating the cause of blown capacitors, respectively.
- Mathematics references occur across all *insight* quadrants: power calculations (*purist*), production efficiency spreadsheets (*doctrinal*), programming algorithms (*situational*) and quantified operator errors (*knower*).
- Across the research case studies, logic-based disciplinary references are predominantly seen in machine building and systems integration sectors where the focus is on designing a custom-made automation system based on the *situation* (determined by a strongly bounded phenomenon – what the system is required to do – in relation to feasibility, financial and resource constraints, for example). Once component and system decisions are made, procedures revolve around the *doctrinal* implementation of specific platforms and programming languages.

Secondly, the different sectors demonstrated problem-solving patterns determined by the scale and organizational structure of the business, as well as the nature of the particular practitioner.

An important finding at systems integration industrial sites is the necessity to be able to move iteratively along the diagonal between multiple possibilities (*situational insight*) and the procedural rules of a particular choice (*doctrinal insight*). A second finding worth highlighting here is the focus on the lower half of the *epistemic plane* in large-scale manufacturing and production environments. Here we see operator error and management decisions (*knower insight*) lying at the heart of the case study problems, in sites where system efficiency is driven by *doctrinal* procedures, such as companies using Six Sigma methodologies, for example. A key implication of this 'sector *insight* preference' finding is that practitioners who had a dominant *insight* orientation opposite to that of the environment often expressed dissatisfaction in their workplace, and were not necessarily as effective as 'code-matching' practitioners at problem solving. One of the recommendations of the research was to urge educators to build sufficient code-shifting opportunities into the curriculum so as to enable access for all engineering students to a broader range of the 'ways of knowing' required for complexity and innovation in the 21st century.

In summary of the PhD and post-doctoral research, key findings demonstrate a symbiotic, structuring relationship between the 'what' and the 'how' of the problem in relation to the problem-solving components (environment, artefacts, practitioner and problem structure). Successful problem solving relies on the recognition of these relationships and the realization of appropriate practice code conventions in context. Successful practitioners engage in explicit code-shifting, generally drawing on existing physics and mathematics-based knowledge, while often acquiring new context-specific logic-based knowledge. High-achieving practitioners across these disciplinary domains demonstrate iterative code-shifting practices and an ability to express their thinking with discursive sensitivity.

V. Engineering Academic Development Cases

The focus of much academic development work is around student learning, as a result of significant research activity in this area for the past century [6]. Engineering education, specifically, has also seen research and conceptual work around the question of 21st century complexity [1] and the necessity to fundamentally shift paradigms [19]. This complexity is ostensibly captured in the International Engineering Alliance graduate profiles [20], which generally inform the design and evaluation of engineering qualifications. However, "much current published literature in engineering education does not proceed from an explicit theoretical basis" [21], nor is there much more than generic graduate surveys or employer feedback to enable educators to approach teaching engineering from a theoretically informed perspective. This is a form of 'knowledge-blindness' [11] which extends beyond simply not understanding that different kinds of knowledge have different "organizing principles" [11] which have implications for teaching, learning and assessment. It is also being blind to theoretically- and empirically-informed research generated in sites of practice beyond education.

The original impetus for the PhD and post-doctoral studies was to understand how the base engineering disciplines play out in real world practice contexts. An initial literature search on a common scholarly search engine revealed literally millions of results for 'problem-solving methodologies', but very little by way of theoretically explicit studies on how engineering practitioners really solve problems, how they engage with disciplinary knowledge in the actual field of practice, and what this might mean for educational decisions.

Given the emergence of a clear disjuncture between 'science and engineering' [22] and a 21st century move away from the traditional science-based curriculum [2], it may be dangerous to ignore the role played by the disciplines [8] in actual complex problem-solving processes. It is crucial for educators to develop their understanding of the relationship between theory and practice, considering both our alarming global statistics on engineering student recruitment, retention and graduation, *and* the Sustainable Development Goals (SDGs), which are heavily reliant on STEM expertise [23]. The engineering problem-solving research described previously provided a golden opportunity to begin to 'close the loop' between theory and practice.

In order to demonstrate the usefulness of drawing on theoretically informed research conducted in empirical sites, I have selected three academic development case studies at two South African institutions. The first two case studies (A1 and A2) are those of individual lecturers within a larger group of ten academics, and the third case study (B) is an entire department consisting of 18 members. Institution A is a medium-sized, traditional, research-intensive university with a reputation for excellence. The engineering curricula here might be described as having strong roots in the foundation disciplines, and teaching is designed around theoretical lectures, tutorials focused on application of primarily mathematics concepts, as well as basic practical laboratory work. With recent increases in student numbers and a greater 'globalization' ethic, the faculty is actively involved in experimenting with technologies to reduce staff workload, improve student learning, and enable better technical skills.

The second institution (B) is a University of Technology catering to school leavers who achieve less than the distinctions required for acceptance at institution A. The institution has progressively begun to focus on research activities as a result of a national shift in this direction as well as funding pressures, and has started to shed its previously more vocational orientation. Engineering retention and graduation rates are low [24], and the institution has faced ongoing student protests for three years.

The following sections detail academic development initiatives where educators have been familiarized with the PhD and post-doctoral research, as well as a number of teaching and learning theories. For the purpose of this paper, the focus is on the use of the LCT *epistemic plane.*

A. *Teaching & Learning across the epistemic plane*

Lecturer A1 teaches Process Control to final year Bachelor's in Chemical Engineering students at institution A. The course covers the principles and behavior of control systems, types of control and controller design, as well as instrumentation and process safety. Prior to 2017, the course culminated in a 3-week plant-wide control design project. Having taught the course for five years, lecturer A1 had made a number of observations, a key one being student difficulties with the transition from the relatively theoretical application of mathematics to solve mass and energy balances into the software space. The institution has a campus-wide MATLAB®/Simulink® license, which is used in the case of the Process Control subject. A first phase in the academic development process was to interrogate the current curriculum and timing of the major assignment [7].

By analyzing the course content, A1 determined that the overarching principle in the course is that of the conservation of mass and energy, which require a strong *purist insight*. Much of the work on mass and energy balance equations occurs in the *doctrinal insight* quadrant. However, given the industry case-study findings from the systems integration sector on the importance of an iterative diagonal shift between the *situational* and *doctrinal insights*, it appeared clear that students did not have enough time to engage on the left-hand side of the *epistemic plane*. Previous student assessments had demonstrated difficulties in shifting from the mathematical work (*doctrinal insight*) to the use of MATLAB®/Simulink® software (*situational & doctrinal insights*).

The identification of these as different forms of knowledge with fundamentally different ways of thinking enabled a restructuring of the curriculum by using the plant design assignment as an anchor across the entire course (figure 3). In this way, students could iteratively work on sub-sections of the design, drawing on the *purist* concepts during lectures and mathematical focus of the tutorials, while practicing in the software space. The intention was to improve students' ability to code shift diametrically.

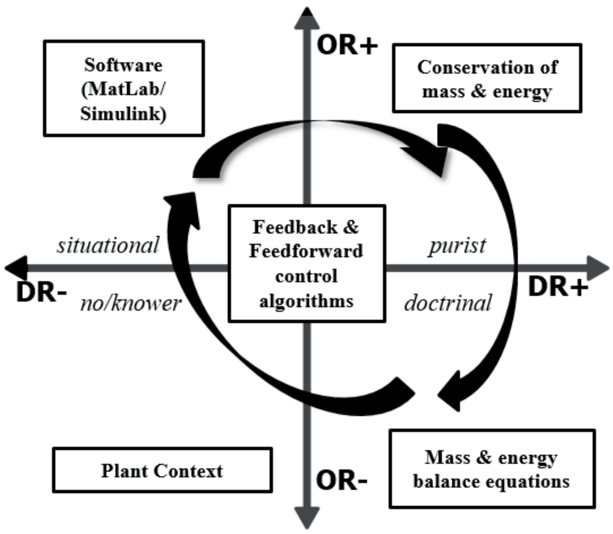

Fig. 3. Lecturer A1 Process Control course analysis on *epistemic plane*

B. Assessment to enable code-shifting

Lecturer A2 teaches first year students (±1000) programming (C). The traditional approach involved hand-written 'coding' assessments (*doctrinal insight*), which invariably resulted in delayed feedback to students and a massive workload for the teaching assistants. As part of a mandatory academic development programme for all new lecturers at the institution, A2 focused on this particular course during our sessions. He had already introduced the Moodle® extension *CodeRunner®* in order to ease the marking workload and to provide students with immediate feedback. *CodeRunner®* is able to handle a number of programming languages, including C, Java, Python, PHP, JavaScript and Octave (Matlab) and is flexible in that teachers can set a range of question types, from 'write a function' to 'write a program' [25].

His encounter with the industrial research and the *epistemic plane* enabled him to analyze which forms of thinking were being exercised in the student engagement with the software (figure 4). In the first place, the fact that the application enables testing of multiple programming languages as well as the construction of various types of questions means that *CodeRunner®* itself is located in the *situational* quadrant. Using it means making choices. With simpler kinds of questions, students learn the *doctrinal* conventions around naming, syntax and commenting, for example. At a secondary level, the iterative practice enables grasp of the fundamental (*purist*) coding principles, such as consistency and simplicity. Given that students engage with the platform in their own time and space suggests that here is a form of learning that can accommodate different student needs (*knower insight*). This is particularly relevant in the South African context which sees significantly different forms of digital access and familiarity prior to entry into the higher education system. The greater flexibility built into the application enables a student to work at his/her own pace on different kinds of questions that develop different kinds of thinking. Effectively speaking, the application provides more opportunity for the bridging of the 'digital divide' between students with different digital literacy levels.

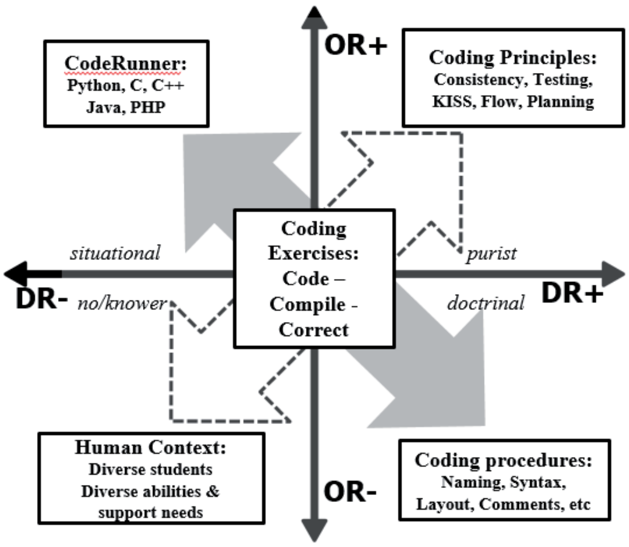

Fig. 4. Lecturer A2 CodeRunner course analysis on *epistemic plane*

Using the *epistemic plane* to understand how the students were being supported in their programming course demonstrated that this was an ideal way in which to enable early code-shifting practices which are to play a major role in industrial practice.

C. Curriculum redesign using the epistemic plane

The third case study is that of the industrial engineering department (Group B) at a University of Technology. Under pressure to meet the deadlines for technician curriculum redesign specifications, which are in alignment with the new Higher Education Qualifications Sub-Framework based on national policy [26], the department has engaged in a collective approach to the task.

The first stage of academic development work entailed an interrogation of the 11 Diploma exit level outcomes as prescribed by the Engineering Council of South Africa (ECSA) [27]. Experience and research have shown that learning outcomes can be ambiguous [28], and open to interpretation. Although intended to guide teaching, learning and assessment processes in the spirit of constructive alignment [6], previous research had revealed that different engineering sub-fields have different perspectives on these outcomes [29]. Group B consists of 18 specialists from mathematics to economics, control systems, operations research and manufacturing engineering.

Table 1. Engineering three-year Diploma Exit Level Outcomes

Exit Level Outcome *(renamed as 'Graduate Attributes' in 2017)*	
1	Apply **engineering principles** to systematically diagnose and solve *well-defined* engineering problems.
2	Apply **knowledge of mathematics, natural science and engineering sciences** to defined and applied engineering procedures, processes, systems and methodologies to solve well-defined engineering problems.
3	Perform procedural and non-procedural **design** of well-defined components, systems, works, products or processes to meet desired needs normally within applicable standards, codes of practice and legislation.
4	Conduct **investigations** of well-defined problems through locating and searching relevant codes and catalogues, conducting standard tests, experiments and measurements.
5	Use appropriate **techniques**, resources, and modern engineering tools, including information technology, prediction and modelling, for the solution of well-defined engineering problems, with an understanding of the limitations, restrictions, premises, assumptions and constraints.
6	**Communicate** effectively, both orally and in writing, within an engineering context.
7	Demonstrate knowledge and understanding of the **impact** of engineering activity on the society, economy, industrial and physical environment, and address issues by defined procedures.
8	Demonstrate knowledge and understanding of engineering **management principles** and apply these to one's own work, as a member or leader in a diverse team and to manage projects
9	Engage in **independent and life-long learning** through well-developed learning skills.
10	Comprehend and apply **ethical principles** and commit to professional ethics, responsibilities and norms of engineering practice within own limits of competence.
11	Demonstrate an understanding of **workplace practices** to solve engineering problems consistent with academic learning achieved.

Using a small-group approach, the larger group was split into four sub-groups and instructed to interrogate the 11 exit level outcomes (table 1) using the *epistemic plane* (which had been introduced in their first session). The discussion around the different outcomes in relation to determining *which* outcomes foreground *what kind of insight* was clearly invigorating, as this was the first time the department had actively engaged with the outcome statements outside of the context of preparing their own subject files for accreditation and quality assurance processes.

Using a color per group, the four smaller groups consolidated their interpretation onto a single 'outcomes map' (figure 5). There was a great deal of surprise when they examined their final allocations. This led to critical engagement with what the '*insights*' really mean for their context and profession. The only two outcomes on which all agreed were 1) that the 'application of engineering principles' entailed all four *insights,* and 2) that knowledge of natural, mathematical and engineering sciences were seen as *purist/doctrinal*. All other outcomes saw different perspectives from the different academic staff: The use of appropriate techniques and tools, for example, was seen as dependent on a *situation*, or procedural, or both *purist/doctrinal*, or dependent on the person (*knower*). Similarly, the ability to 'conduct investigations (Outcome 4) was situated in all four different *insights.* This difference of perspective from a single department suggests that the attempt to align assessment criteria (where all have different tacit understandings of what counts) may not provide the required level of reliability [30].

What this exercise confirmed was not only that each academic is a *knower* in his/her own right with different perspectives on concepts, but that this may well be the experience of their students – different conceptions of what they are learning, with the academic staff member assuming that terms and concepts used are standard. This highlighted the need to make not only interpretations, but also the appropriate '*insight* codes' explicit.

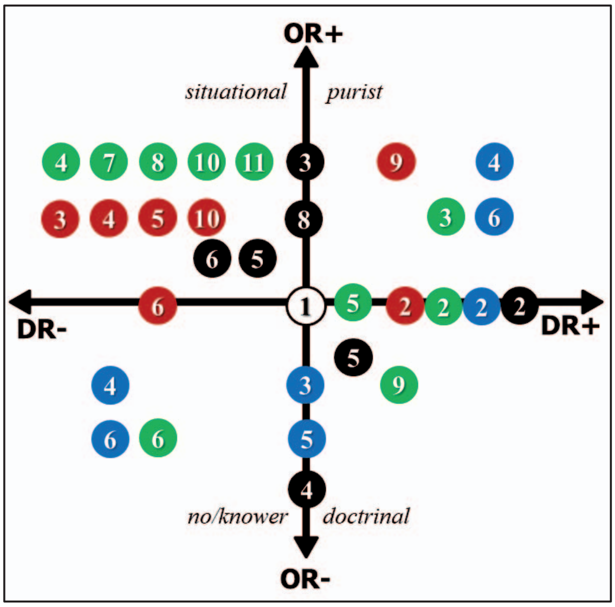

Fig. 5. Group B interpretation of Exit Level Outcomes on *epistemic plane*

Secondly, the exercise confirmed that *all the outcomes* probably entailed *all the insights*, to varying degrees and that it is important for educators to take responsibility for building a range of abilities into their subject areas. A key revelation for the group was the number of outcomes situated on the left-hand side of the *epistemic plane* and the fact that it is precisely in this area that most employer complaints are situated – lack of technical skills and the so-called 'soft skills' around dealing with people. This suggested that more thought needed to go into integrating these *insights* into the curriculum.

The second phase of the academic development program with Group B involved a detailed subject level analysis. A key feature that emerged was that much of the content of their courses was being taught procedurally (*doctrinal insight*) and accompanied by a few select scenarios (*situational insight*) in which to 'apply' the procedures. However, the fundamental principles (*purist insight*) were not being foregrounded. This was only identified when staff interrogated their curriculum documents and allocated aspects of subject areas to the different *insight* quadrants based on *what* and *how* they were teaching that particular aspect. For the most part, subject 'content' such as Work Study or Operations Research aspects were written into the *doctrinal* quadrant accompanied by verbs indicating procedural action (apply, quantify, calculate) and methods. Subject assignments were usually allocated to the *situational* quadrant, since these are generally 'scenarios' in which to apply the 'methods'. The final design-oriented projects are cause for concern in the department, since it is here that students struggle the most and the subject sees a poor pass rate. In light of the industrial problem-solving research findings, staff could see the relationship between the students' poor design performance and the lack of ability to code shift.

It emerged through the ensuing discussion that the reason for the primary focus on methods is the low level of school-leaving achievement with which their students are accepted onto the program, particularly in mathematics and digital literacies. Staff expressed feeling frustrated and having to resort to 'drilling and practice' of methods. The *epistemic plane* and iterative code-shifting evident in the successful graduate problem-solving case studies highlighted 1) how important it is to enable students to shift between different forms of thinking, and 2) that the *epistemic plane* can aid in iteratively scaffolding learning even for students who require more foundational support. The department realized that their focus on the *doctrinal* and *situational* meant students were being taught *how* and *what if*, but not '*why*'.

Literature highlights the predominance of discipline-based experts' tacit knowledge [30] and their assumption that students grasp the principles behind the formulaic representation of those principles (such as equations or formulas). What has been apparent in a number of engineering academic development workshops is staff inability to either articulate or agree on what exactly is meant by 'engineering principles'. Depending on their disciplinary orientation, one hears everything from "a fundamental engineering principle is to reason from 'first principles'" to "safety, efficiency, cost-effectiveness" and systems-thinking or problem-solving. An illuminating feature of the *epistemic plane* as an analytical tool is that even here one could allocate *kinds of principles* to the different *insight* quadrants, from *purist* 'first principles' to *doctrinal* 'standards' or *situational* 'systems-thinking' and *knower*-oriented 'safety'.

In the case of Group B, it was clear that as a team they needed to collectively engage with the question of 'principles' in relation to the purpose of the qualification they are busy redesigning. As in the case of iterative engineering design, the third phase necessitated a return to the beginning with a simplification of the *epistemic plane* to allow staff to really interrogated the what was important to enable their students to accomplish. Their brainstorming is illustrated in figure 6.

This workshop phase enabled the team to take collective ownership of the process of interpreting and motivating perspectives on the kinds of outcomes that matter in their field and in their context. The use of the *epistemic plane* as a 'mediating device' or 'translation device' [11] was particularly effective in that it demanded a form of code-shifting similar to that experienced by their students. The engineering staff were thinking in different kinds of ways with tools from a different discipline (sociology). Stepping away from their curriculum, outcomes and standards documents enabled them to think critically about what really matters. I observed from their discussion that employability is a key concern, and is accompanied by broader objectives such as students' needing to develop awareness of the greater environment, human factors and a respect for 'rules' governing our co-existence. An important moment in this third phase was the collective decision that 'Ubuntu' is a key principle. The word means "human mutuality" and implies a shared humanity [31]. This term transcends those captured in the formal qualification specifications, and speaks to the emergence of a shared philosophy in the department.

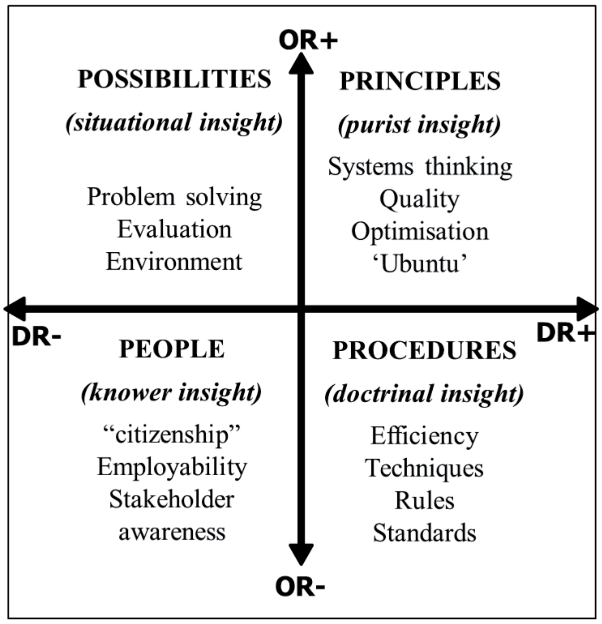

Fig. 6. Group B *epistemic plane* interpretation of 'principles' for industrial engineering graduates

VI. Conclusion

The background to this paper established the challenge facing engineering educators as the pressure to prepare students for complex engagement with theory, practice and technologies in evolving 21st century workplaces. It was suggested that one important element in engineering educator professional development lies in theoretically-informed and empirically-generated engineering education research from industrial practice sites. Such research enables educators to develop an understanding of real problem-solving practices that go beyond text-book applications of methodologies.

Using a tool from Legitimation Code Theory, a number of educators were inducted into the application of the *epistemic plane* in order to interrogate their existing curriculum, teaching, learning and assessment practices. A key finding from industrial research is the importance of understanding that the principles, procedures, possibilities and people involved in any knowledge practice have different 'organizing principles' [11], and that code shifting between these different aspects is the key to successful problem solving. The problem-solving patterns that emerge highlight the significance of context.

The professional/academic development initiatives undertaken with educators from the research-intensive institution (A) enabled a focus on the different forms of thinking required when using different kinds of software and platforms. The analyses here demonstrate the iterative diagonal code shifting between the more open-ended possibilities and the fixed 'rules' for each possibility. Enabling their students to consciously practice this shifting in an iterative fashion – while simultaneously strengthening their understanding of key principles - better prepares them for technology-based practices in the workplace, as evident in the industry case studies presented to the educators. The conscious, iterative shifting occurs by way of extending an assignment or project over time (example A1) and returning to key principles and associated procedures regularly. Alternatively, as in the case of A2, students consciously cycle between possibilities and procedures with the effective use of software to enable programming familiarization.

In the case of institution B - the University of Technology - the development initiative with an entire department encouraged them to shift out of their engineering disciplinary comfort zone into that of sociology. They were literally required to think with a different set of tools. This code-shifting strategy took the educators from the right-hand side of the *epistemic plane* into the more open-ended side, drawing on different approaches in order to reaffirm how important it is to be clear about the underpinning principles in specific contexts. The strategy mimics the way their students may perceive different subject areas and different engineering practices. The opportunity to collectively interrogate and subsequently agree on the 'what' and 'how' elements of the overall curriculum also afforded each staff member the opportunity to share his/her subject area expertise and offer insights to colleagues.

These case studies demonstrate a theoretically-informed 'closing-the-loop' approach to enhancing engineering educators' conceptual understanding of the complexity of both the engineering profession and the role of education.

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