Integrating multidisciplinary engineering knowledge

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Abstract

In order to design two distinct engineering qualification levels for an existing University of Technology (UoT) programme, empirical evidence based on the current diploma is necessary to illuminate the nature of and the relationship between the *contextual* and *conceptual* elements underpinning a multidisciplinary engineering curriculum. The increasing focus on contextual application could result in decreasing opportunities to develop the conceptual disciplinary grasp required for a dynamic, emerging region at the forefront of technological innovation. Using the theoretical tools of Bernstein and Maton to analyse final year student practice, the research addresses the question of how multidisciplinary knowledge is integrated by students, and what this reveals about the nature of such knowledge. The paper presents a conceptualisation of multidisciplinary knowledge integration practices as a dynamic process along two axes simultaneously, shifting between different forms and levels of conceptual and contextual knowledge.

Keywords: engineering education; multidisciplinarity; knowledge structures; sociology of higher education curriculum; praxis

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Introduction

The current curriculum typology and institutional differentiation debate in South African Higher Education is centred around the weighting of theoretical and practical knowledge requirements in order to differentiate between qualifications. Muller (2008) outlines four potential occupational fields and their qualification routes using a continuum based on the internal characteristics of curriculum structure that frames the theory/practice divide in 'conceptual'/'contextual' terms. Conceptual coherence curricula (the professions) "presume a hierarchy of abstraction and conceptual difficulty", whereas contextual coherence curricula (the occupations) "are segmentally connected, where each segment is adequate to a context, sufficient to a purpose" (Muller 2008, 21). These two broad typologies are proving problematic for applied fields such as engineering, particularly for the Universities of Technology (UoTs) whose explicit links to industry and curriculated Work-Integrated Learning components imply a more 'contextual' application of knowledge, and by extension, therefore, a lower level qualification. The focus of this paper is the region of Mechatronics Engineering, which is essentially the computer control of an electro-mechanical system. Such regions are highly dependent on rapidly evolving Information and Communication Technologies (ICTs) produced by industry, which necessitates increasingly context-specific engagement with the new technologies, and hence an increasingly contextual curriculum. However, the engagement with such technologies in the design and optimisation of engineering systems requires a capacity to integrate a range of knowledges as well as a grasp of innovative potential, and "generalisable innovation relies on conceptual knowledge" (Muller 2008, 26). This suggests that the differentiation of qualifications along conceptual/contextual curriculum structural lines in emerging multidisciplinary engineering regions may not be that straightforward, and what is required is an examination of what precisely these descriptors mean.

The curriculum in formal education is the platform which facilitates the transition from knowledge to practice. However, although a “curriculum defines what counts as valid knowledge” (Bernstein 1975, 85), it is constructed through a process of ‘recontextualisation’: the delocation, transformation and relocation of knowledge as part of pedagogic discourse (Bernstein 2000). Mechatronics engineering curricula are typically constructed by drawing from knowledge areas that span the conceptual/contextual curriculum continuum: from the pure disciplines (such as physics and mathematics), ‘regions’ (such as Mechanical or Electrical Engineering), and ‘subject areas’ created to allow for the integration and application of knowledge specific to the emerging region (such as Computer-Aided Manufacturing). Not only are curriculum content decisions informed by stakeholders hailing from various sub-disciplines, but the ever-widening ambit of increasingly divergent contexts of application means that ‘segmental’ contextually-coherent curricula run the risk of not facilitating precisely the ‘conceptual grasp’ required to cope in a dynamic technologically-orientated region. ‘Collection type’ curriculum structures may not “foster an adequate, sufficiently subsumptively integrated” (Bailey McEwan 2009, 72) understanding of the underlying concepts. There are two implications to the notion of ‘concept’ here. On the one hand there is “the vertical spine of the parent discipline” (Muller 2008, 26), and on the other hand an explicit “relational idea” (Bernstein 1975, 83) that applies to the region as a whole. The suggestion that “regions and contextual coherence curricula benefit from having a conceptual coherence or disciplinary core” (Muller 2008, 23) is made all the more complex when the region draws on disparate disciplines (each with its own form of ‘verticality’). What exactly is the ‘disciplinary core’ of a region such as ‘Mechatronics Engineering’?

A consequence of the lack of a coherent disciplinary core and the pervasive ‘collection type’ curricula in emerging regions (beyond even that under discussion here) may be seen in the widespread evidence of the difficulties experienced by students in integrating knowledge, particularly in the ‘design’ subjects in such regions. Given that such curricula undergo complex recontextualisation processes over time, the underlying cause of knowledge integration difficulties may lie in the fact that curriculum stakeholders have underestimated the complexities of the nature of the conceptual and contextual aspects underpinning a multidisciplinary curriculum. The paper draws on findings from a broader research project in which a single case study approach was adopted, using a Bernsteinian conceptual framework and methodologically pluralist research process which entailed a multilevel examination of final year Mechatronics diploma student practice as manifest in texts, interviews, observation and assessment. The intention of this paper is to describe the analysis of the nature of and relationship between the *conceptual* and *contextual* elements of student praxis as evident in their engagement with and successful[1] solving of a particular design problem which required the different forms of knowledge to be integrated. The analysis entails two steps. Firstly, in order to understand the implications of integrating knowledge, an understanding is necessary of what that knowledge is. The application of Bernstein’s theories on knowledge structures demonstrates that there are fundamentally different kinds of knowledge in this region, whose epistemological origins have become blurred under generic labels such as the ‘engineering sciences’. The second step is to look at *how* students work with this knowledge in a specific context. Using Karl Maton’s

1 The focus of this paper is successful knowledge integration and not student difficulties. Although these formed part of the research, they are reported elsewhere.

concept of *semantic gravity* (2009), a tool has been developed to look at what form of conceptuality actually emerges in practice, and what degree of context-dependency is evident. The relationship between the conceptual and contextual in this emerging region suggests a form of conceptuality not accommodated in current curriculum typologies and qualification descriptors.

Mechatronics knowledge structures in the curriculum

> "Mechatronics Engineering is the concurrent design, manufacture, integration and maintenance of controlled dynamic electro-mechanical systems" (MEFSA, Mechatronics identity 2011).

Epistemologically, a Mechatronics curriculum comprises a range of subjects that are fundamentally different in nature and which require very different learning and application practices. This has manifested in widespread cases of the difficulties in integrating knowledge in this region. Bailey McEwan (2009) highlights the difficulties faced by Mechanical and Electrical Engineering students at a traditional South African university, where the focus is on the physics-based aspects of the relationship between mechanical and electrical systems. Globally, Mechatronics programmes are generally seen as an extension of either Mechanical or Electrical Engineering and it is here that physics and mathematics appear to be unproblematically regarded as the epistemological basis of Mechatronics Engineering. Lyshevski (in Bishop, 2002) shifts the focus to a different dimension: "There is an increase in the number of students whose good programming skills and theoretical background match with complete inability to solve simple engineering problems" (ibid., 68). This suggests there may be a difference between programming and engineering 'skills'. At Bucknell University (Shooter and McNeil 2002) course designers had to introduce a more user-friendly programming language as Electrical and Mechanical Engineering students had difficulty in grasping the ‘assembly’ language required for mechatronic systems. The empirical evidence of the difficulties in integrating knowledge in the region clearly establishes that Mechatronics is broadly based on three regions: mechanical, electrical and computer engineering. The notion of ‘conceptuality’ in the region, however, appears to be trapped within a physics-based paradigm. Almost half of the first two years of the current Mechatronics curriculum at the research site (represented in Figure 1) is dedicated to traditional physics-based subjects, with the remaining subjects being mathematics and a collection of contextual, applied technology based subjects.

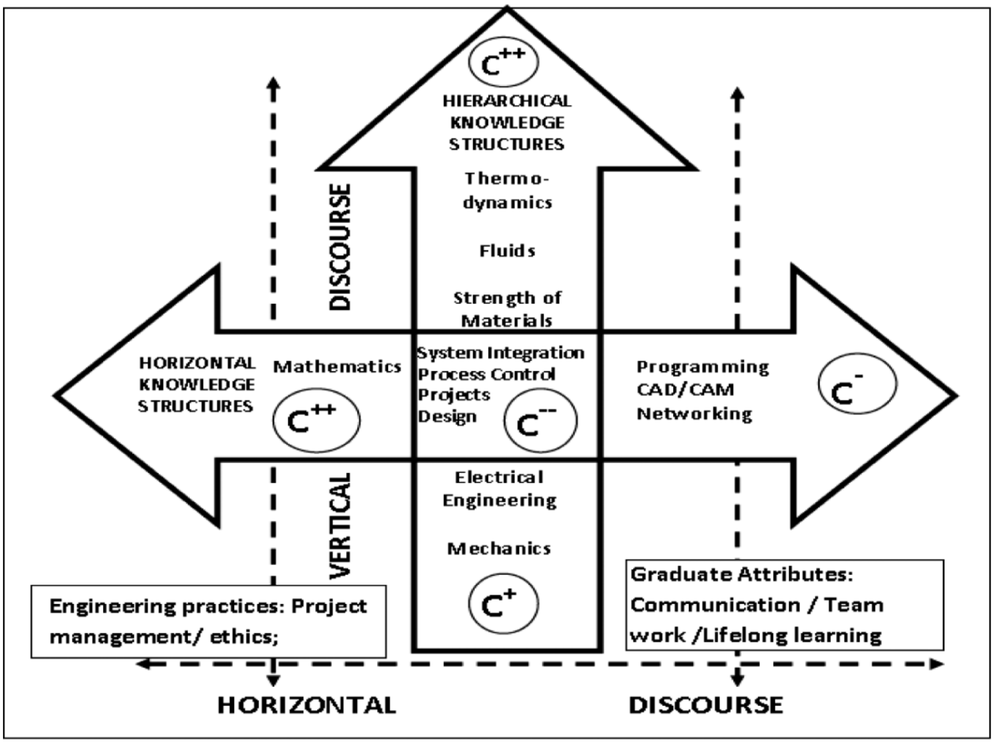

Figure 1. A Mechatronics curriculum knowledge structures and classification.

The differences between these subjects can be described by their structural principles. Hierarchically structured knowledge “attempts to create very general propositions and theories, which integrate knowledge at lower levels” (Bernstein 2000, 161) and is characterised by ever increasing abstraction. The ‘internal characteristics’ that generate progress in knowledge with a hierarchical structure, such as physics, are described as a theory-integrating form of 'verticality' (Young and Muller 2007, 189). These would be the characteristics of the theoretical content of the core mechanical and electrical engineering subjects in the current Mechatronics curriculum as indicated in the upper and lower regions of the central vertical band in Figure 1. Conceptually, hierarchically structured knowledge is highly dependent on systematic sequencing and subsumptive progression over time, often based on fundamental principles formally introduced as early as primary school.

In contrast, horizontally-structured knowledge exhibits 'theory-proliferating' forms of verticality as they "consist of a series of specialised languages with specialised modes of interrogation and criteria for the construction and circulation of texts" (Bernstein 2000, 161). The difference between horizontal knowledge structures can further be described in terms of 'grammaticality': "how theoretical statements deal with their empirical predicates" (Young and Muller 2007, 188). Those horizontal knowledge structures "whose languages have an explicit conceptual syntax capable of relatively precise empirical descriptions" (Bernstein 2000, 163) exhibit strong grammaticality, such as mathematics and 'logic', as opposed to the weak grammaticality of the social sciences where the "capacity of a theory to stably identify empirical correlates" is weaker (Young and Muller 2007, 188). The acquisition of horizontally-structured knowledge has implications for the allocation of time in that "masses of particulars" (Muller 2008, 15) need to be learnt independently, more often than not in a specific context, and each with its own particular form of grammaticality.

Whilst it is important to remember that "a knowledge structure is not necessarily a curriculum structure" (Maton and Muller 2006, 27), the focus of this paper is the way in which the different types of curriculum knowledge are integrated in practice. This can be influenced by the manner in which the forms of knowledge are encountered in a curriculum. *Classification* (Bernstein 2000) may be defined as the degree of boundary maintenance established by specialists in a field that gives something its unique identity and separates it from other disciplines. The Mechatronics curriculum, as experienced by the students at the research site prior to the third year of self-regulated project-based learning, entails a strong classification of the physics-based subjects, as well as mathematics. In contrast, Programming is weakly classified as it draws on the principles of language, logic and mathematics, and is mainly applied to micro-controllers or Programmable Logic Controllers (PLCs). In this study Programming is considered to have a horizontal knowledge structure[2] in that there is no general integrating proposition or general theory. The disciplinary basis is fundamentally that of 'logic', which "is the study of inferences that depend on concepts that are expressed by the 'logical constants,' including... propositional connectives such as 'not,' 'and', 'or', and 'if-then'" (Dictionary.com 2011). Although many programming languages are context-dependent, any one of a number may be used to accomplish the same objective. As with mathematics, each has its own distinctive form of what Bernstein terms a 'strong grammar'. More recently, however, programming language platforms have evolved to allow a user to incorporate different languages for different functions in 'mixed modality' form. This typically includes graphic representations and text type instructions, even to the point of using natural language technology "to allow its users the freedom of programming a device in his/her own natural form of communication" (Wright 1999, 2). This 'mixed modality', which has emerged in response to "the

2 In both Bailey McEwan and the SANTED Engineering curriculum report (2010), all programming related subjects have been classified as hierarchically structured. I believe this is erroneous, and can be tested against the application of Bernstein's explanation of the difference. Bernstein himself classified 'logic' as horizontal (Maton and Muller 2006, 25). I believe that it is precisely this mis-classification of knowledge structure that has made it difficult to identify the problems of knowledge integration in the emerging region.

human-computer interactive element" (ibid.), is in itself a 'new language' and possibly represents a weakening of the grammaticality of the individual languages. These developments highlight the seriality and potential redundancy of programming languages, features particular to horizontal knowledge structures as a result of contributors having "no means of insulating their constructions from their experience constructed by Horizontal discourse"(Bernstein 2000, 166). In other words, these features emerge in response to demand or market driven imperatives not intrinsic to the singulars. Keeping up to date with constant changes in this dynamic region requires ongoing exposure to and accumulation of languages as befits each new context of application. Programming (and, hence, 'logic') represents the knowledge domain at the heart of Mechatronics engineering, in that it is the manner in which *control* of a dynamic electro-mechanical system is executed. If "conceptuality is driven by conceptual innovation in the knowledge structure itself" (Muller 2008, 27), then the conceptuality underlying physics-based regions takes on a subsumptive/reductive form of verticality, whereas the conceptuality in 'logic'-based regions is proliferative.

What this means is that the knowledge structures underpinning the electrical and mechanical engineering subjects (hierarchical) in the emerging region of Mechatronics need to be seen in relation to aspects of control, and thus programming (a horizontal knowledge structure). However, mechanical, electrical and programming knowledge alone still do not constitute 'Mechatronics', which is the control of a dynamic electro-mechanical *system*. In the curriculum, *systems* are encountered in the weakly classified 'subjects' (C^-) such as Mechatronic systems (physical) and Networking (abstract). The former is predominantly concerned with technologies used in the automation of any process, and the latter is the means of enabling communication between these technologies (employing ICTs). In addition to the relatively 'applied' exposure to these technologies, the curriculum includes weakly classified (C^{-}) subjects such as Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM), which are encountered as highly procedural, computer-based applications of knowledge drawn from mathematics and programming. All together, both the strongly and weakly classified subjects, and the hierarchical and horizontal knowledge structures represent the emerging region called Mechatronics engineering, and the subject in which this synthesis manifests itself is Design (C^{--}).

Semantic Gravity

Karl Maton, in extending the work of Bernstein, has developed a number of tools to "help excavate the underlying principles generating forms of knowledge" (2009, 46). One such tool is that of 'semantic gravity', which is a means to reconceptualise "knowledge practices in terms of the degree to which meaning relates to its context" (ibid.). This is an approach through which the 'verticality' of a knowledge structure (whether hierarchical or horizontal) can be described. Maton has devised an external language of description whereby texts can be analysed using the following codes:

Table 1. Maton's language of description for semantic gravity.

Weaker	Abstraction
	Generalisation
	Judgement
	Interpretation
	Summarising description
Stronger	Reproductive description

The strongest form of semantic gravity, 'reproductive description', refers to meanings which "are locked into the context", and the weakest form, 'abstraction', sees meanings as "decontextualised [...] to create abstract principles for use in other potential contexts" (Maton 2009, 48). Maton suggests that *cumulative* knowledge-building is dependent on "the capacity to overcome semantic gravity" (ibid.), in other words to achieve levels of conceptuality that are not context-dependent. In order to recontextualise and transfer knowledge across contexts and over time” a “wave of strengthening and weakening semantic gravity [is] required” (ibid., 5). Maton’s relative topology offers the possibility of analysing the knowledge integration process at the level of classroom practice. By mapping the sequence of the application of hierarchically and horizontally structured knowledge elements in students’ design practice over time, a ‘semantic wave’ may emerge which could shed light on the relationship between different forms of knowledge and the form of conceptuality evident in student practice in this complex region.

Development of the external language of description in context

In the final year of the Mechatronics diploma programme, students work in a simulated professional environment, resembling an automated, high-tech factory. They are entirely responsible for their own learning and schedule, expected to teach themselves a number of new automation technologies, as well as a group ‘design & manufacturing’ project. Evidence of all their work is uploaded weekly to their individual websites along with a full, reflective timesheet detailing all this work. The findings for this paper are drawn from these student texts, observation and interviews based on a single case study, one project group (representative of the programme’s student base) who demonstrate differentiated academic as well as problem-solving abilities.

The case study group of four students from the 2011 first semester cohort were selected on the basis of an initial analysis of ‘knowledge maps’ (hand-drawn interpretations of what students identified as relevant knowledge for the semester) generated by the entire cohort (20 students). These ‘maps’ indicated that students referred to both ‘knowledge’ and ‘practices’ drawn from two different sites: on the one hand those clearly related to the systems or technologies of the region itself, and on the other hand, the knowledge and practices external to the region, in other words, generic engineering, social or professional practices. In order to code these references, Maton's semantic gravity continuum was adapted as illustrated in Table 2.

Table 2. Adaptation of Maton's language of description for semantic gravity.

Weaker	Abstraction	Making statements about the underlying principles or concepts that are non-context-bound
	Generalisation	Drawing a general conclusion to make statements about the system in a broader or cross-context
	Judgement	Drawing a specific conclusion, making a decision that affects the thinking/working process
	Interpretation	Identifying a problem; interpreting something as significant and requiring action (drawing a parallel with other systems/machines; use of metaphor)
	Summarising description	Object-orientated summary/overview of machine/ system/process
Stronger	Reproductive description	Object-orientated procedural description of machine/system/process

The types of knowledge referred to by all the students in the knowledge map exercise were identified and coded as in Table 3.

Table 3. Mechatronics knowledge categories.

Knowledge (code)	Structure (Hier. ↑/Horiz.↔/Mixed +)	Description
MEC	↑↔	Mechanical (theory↑; procedures ↔)
ELE	↑↔	Electrical (theory↑; procedures ↔)
PHY	↑	Physics
LOG	↔	Logic (programming/networking)
MAT	↔	Mathematics
GEN	↔	Generic engineering/academic/social practices
SOC	↔	Social knowledge/experience in the world
SYS	+	Integrated system/machine
CON	+	Integrated control

The focus of analysis, however, were both the reflective time sheets and the texts arising out of interviews with the students. These captured the description of problem-solving over time. In order to reflect the two different sites of references, a praxis code was introduced as follows: Pi refers to knowledge practice procedures internal to the machine/system of the region itself; Pe refers to practices external to the machine/system. By coding the references to different types of knowledge (Table 3) at different degrees of context-dependency (Table 2), a *semantic wave* of knowledge integration over time emerges (Figure 2).

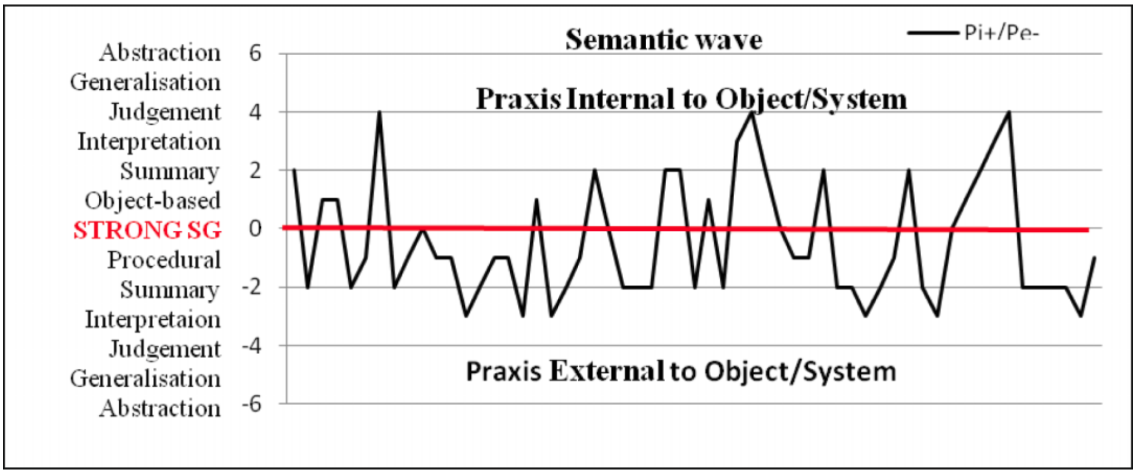

Figure 2. Applying the adaptation of Maton's semantic gravity continuum.

The horizon (0) represents the strongest point of semantic gravity. Knowledge practices related to the object/system from a potential disciplinary perspective are scaled using positive numbers (1 to 6) representing the stages on the continuum. Knowledge practices related to the world outside the object/system are scaled using negative numbers (-1 to -6) where the 'height of disciplinary abstraction' in the upper realm equates with a 'depth of understanding' outside the discipline. As part of the broader research project, the students' knowledge maps as well as weekly time sheets were coded in order to generate a graph to establish a mapping of the individual student's *semantic wave*. The third level of analysis, and focus of this paper, is to apply the tool to problem-solving description over time in order to establish a collective *semantic wave* which reflects mechatronics knowledge integration in practice.

Integrating multidisciplinary knowledge

The analysis focuses on one particular complex problem as described in three problem-solving moments in which the students explain how they tackled certain challenges. This interview approach allows for reflexive articulation, a capacity which in itself suggests a form of conceptuality. The key problem on which the students are working is how to achieve efficient motion in an air-powered vehicle they are designing and constructing for an international competition. Once motion is achieved the vehicle needs to be programmed to autonomously follow a figure of eight and complete as many laps as possible on a race track. Most of the equipment and technologies are donated by the hosts (leading global automation specialists) and students are constrained by these.

Interview 1: motion problem

The first semi-structured interview with the group saw a focus on how they were going to achieve motion using what are called ‘muscles’. These are air-powered tubes which can contract and expand in such a way as to ‘drive’ a shaft. The interview begins with student L describing, in object-orientated detail, the position and nature of these ‘muscles’ in the immediate structural context (mechanical). Student P explains that the movement is restricted to a range of about 10 – 20mm, and that “the second it comes past the maximum extension, it's losing energy to the expansion and then you have minimum torque because of the position of the shaft in relation to the central pivot point”. This clarification of the underlying physics principles (turns 8-11) then leads to the third student, T, explaining that they have thought of using a one-way bearing, based on his knowledge of hunting with a ‘cam bow’ (turns 14-16). This represents drawing on knowledge situated outside the immediate region, a move repeated by student L, who has suggested the addition of a bicycle gearing system (turns 18-20). At this stage of the problem, the focus is on the structural (mechanical) elements, the underlying physics principles of which are detailed by student P. What is noteworthy is that two of the moves towards general technical principles (Pi 5) flow from interpretation (-3) and judgement (-4) in the Pe region, based on students’ experiences of systems encountered in their social environments, as well as their ability to apply physics principles to the real world.

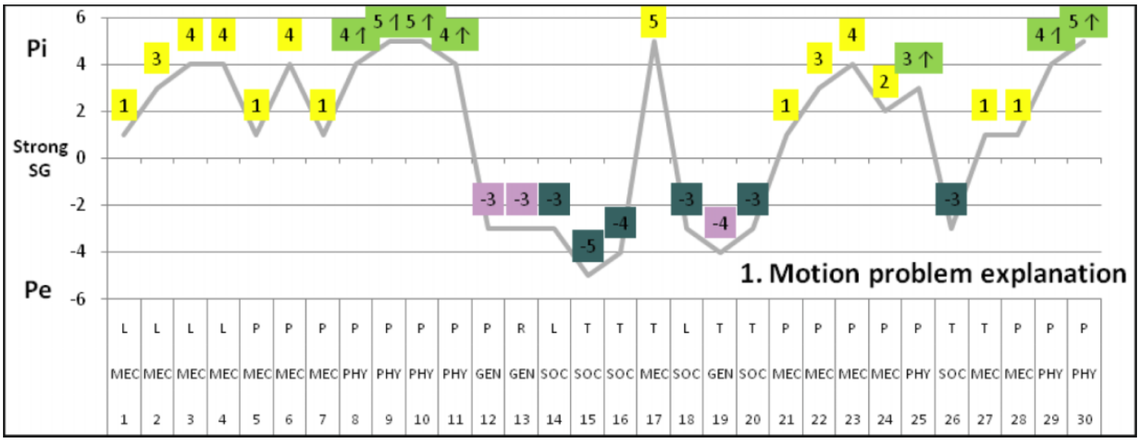

Figure 3. Interview 1 group semantic wave.

Interview 2: motion solution

With the structural system in place, the design focus shifts to the problem of steering the air-powered vehicle. The second interview features students P and R explaining their decision to use a pulse width modulation technique (PWM) to program the steering process. “With PWM comes a new method of positioning servos. Using a method where you are pulsing one side and the other side with different rates and that creates a pressure differential and then movement” (turn 45). This explanation highlights the difficulty of determining what disciplinary knowledge is implied. Essentially PWM is “a way of digitally encoding analog signal levels... [where a] voltage or current source is supplied to the analog load by means of a repeating series of on and off pulses” (Barr 2011). As these signals are related to a change in voltage, the underlying principle is one of *physics*. However, the rate of change needs to be determined using *mathematical* calculations. Furthermore, in a digital control context such as this project, the focus is on programming the system to respond to the ‘rules’ of *logic programming.* This use of PWM represents a perfect synthesis of the collective underlying disciplinary foundations of Mechatronics. As can be seen in the semantic wave depicting this interview (Figure 4), the knowledge references move from the mechanical structural elements to physics principles, then mathematics and finally logic. In turns 48-49, student P refers to the PWM mathematical algorithms he had previously demonstrated on his computer. These are essentially the abstract representation of the relationship between differential pressure points and movement.

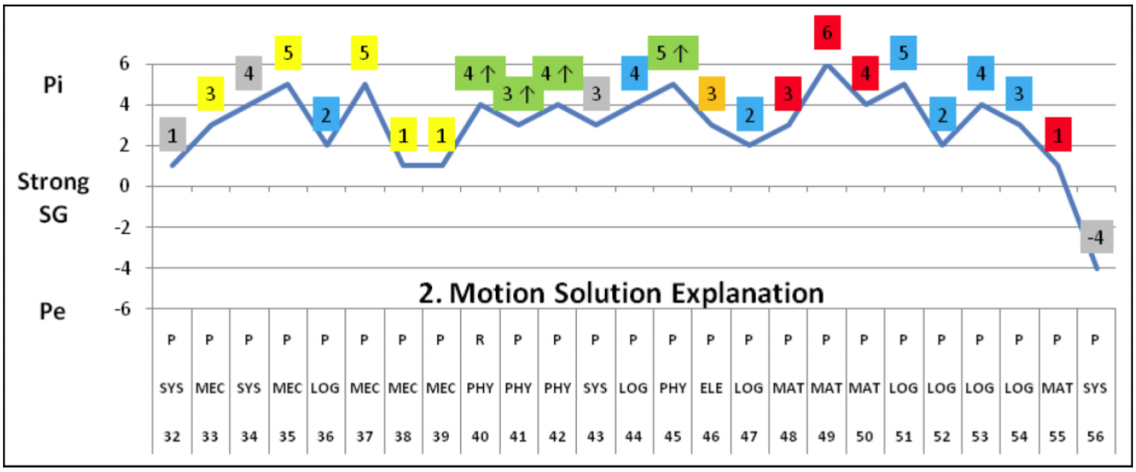

Figure 4.1 Interview 2 semantic wave.

PWM is not taught on the programme and their decision to use it was facilitated by hours of Internet research (reported elsewhere). The Internet is not only the predominant source of new knowledge relevant to the region, but also represents a knowledge practice situated outside the region (Pe) in that it requires a particular expertise to navigate this ubiquitous information platform, and subsequently locate and make effective use of the requisite information. Although they do not refer to this fact during this particular interview itself, there are several references in the students' weekly time sheets which detailed their work on an hourly basis.

Interview 3: System control solution

The final stage of the complex motion-control problem is the actual programming of the vehicle. As with student P, student R is able to climb into the inner logic of how this system should work, explaining that the vehicle has to 'differentiate' between different lines to enable it to follow a track in the figure of 8 until such time as it needs to refuel via a pit-lane, after which it cannot re-enter this lane as it is only on the one side (turns 66-73). This means the vehicle has to be programmed (instructed in a number of languages) to recognise certain conditions and respond to them, all the while being steered autonomously through PWM (turns 76-80) and driven by pressurised air which is contracting and expanding 'muscles' driving a one-way bearing shaft attached to the wheels. Epistemologically, this explanation represents the integrated system as a whole, which has embedded within it principles of mathematics, physics and logic, which principles have now become hard to separate. In turns 82-83, the student highlights the challenges entailed in grasping this synthesis: "the difficulty is ... figuring it out in theory before you go to program it" and he emphasises the need to concentrate "in order not to lose sight of what has been done and what needs to be done". This speaks to an underlying principle applicable not only to the region, but to any complex problem. The pattern in each of the interviews appears fairly consistent. They begin in an object-orientated context, with several procedural phases in which decisions are made (judgements). Students T and L generally (in interviews for the broader research project) make references to drawing on knowledge in the world outside of the region. By the same token, students P and R are quick to evidence a move away from the

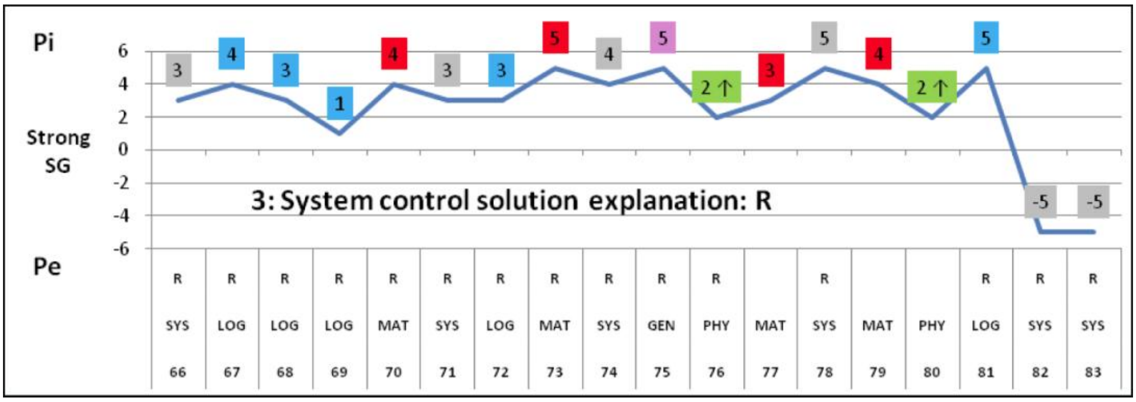

Figure 5. Interview 3 semantic wave.

immediate context to the abstraction of the sciences. The interviews attempted to establish the nature of the epistemic bases of the knowledge on which these students draw in specific instances, and the degree of context-dependency (verticality) evident in their explanation of solving these problems.

A graphic summary of the interviews (Figure 6) visualises the application of knowledge to solving a complex problem in the design process of mechatronic systems.

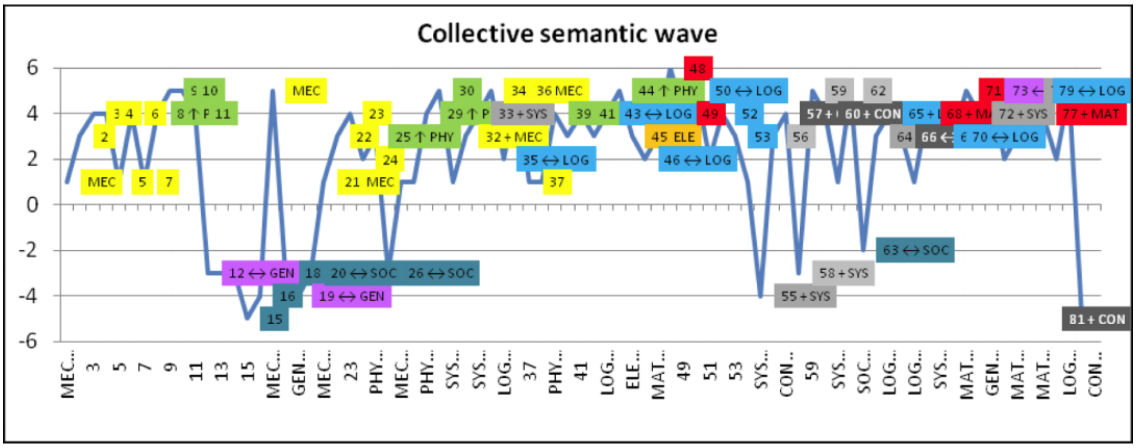

Figure 6. Collective semantic wave.

What the interviews appear to indicate is that integrating and applying knowledge in Mechatronics engineering is essentially the ability to draw on knowledge from different disciplinary/regional areas, and build the knowledge cumulatively by moving (in wave form) up and down a context-dependency scale of semantic gravity. The separable contextually visible disciplinary regions are mechanical, electrical and programming, and they generally flow in this order. Over time, however, they merge into a ‘system’. One can see this develop in Figure 6, where from turn 55 onwards there are increasing references to the ‘system’. Likewise, the conceptual disciplinary core of these (physics, mathematics and logic) merges into ‘control’.

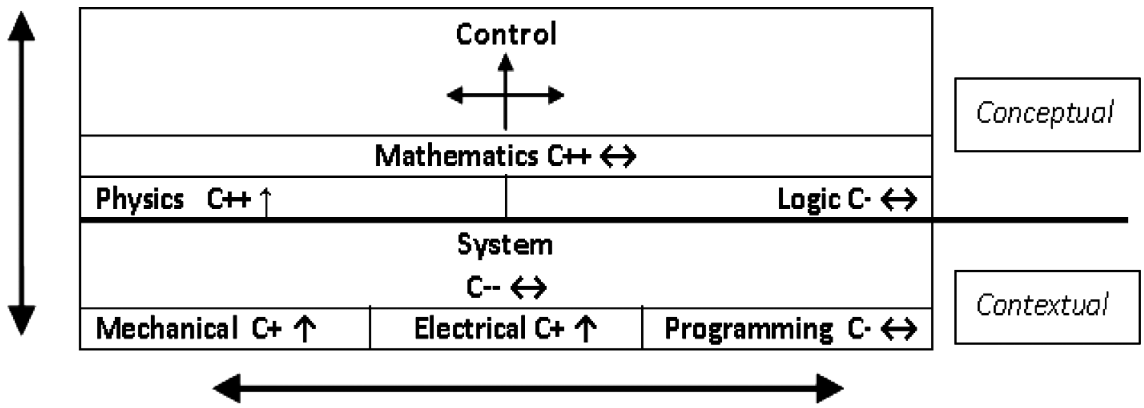

Figure 7. Mechatronics knowledge levels.

As the design process develops, it becomes increasingly difficult to isolate those elements in the lower part of Figure 7. However, the more complex the problem in the ‘system’, the more important it is to be able to isolate the specific area that requires a solution, hence the need to identify whether or not it is a problem of physics (such as the differential pressure principles described in turns 40-45) or mathematics (the calculations for PWM in turns 48-50) or logic in relation to *system control* (turns 78-81). Practically, a problem at the system and control stage could point to a structural flaw, which would mean a return to ‘mechanical’ elements. Similarly, a problem could point to a power miscalculation, thus ‘electrical’. This suggests that integration of Mechatronics knowledge occurs along two axes in a non-linear fashion. The collective semantic wave demonstrates the overall progression (left to right) from the structurally visible system (mechanical/electrical) to the ‘integrated system’, which includes the invisible dimension of the embedded system (programming language). Each of these *contextual* aspects can further be interpreted as vertically *conceptual* as they entail the principles of the core disciplines: physics, mathematics and logic. When these knowledge structures are regarded in isolation (such as in strongly classified subjects in a curriculum), they are interpreted as mono-directional (either hierarchical or horizontal). The synthesis in practice, however, suggests a *dynamic bi-axial knowledge structure*, with shifts in verticality dependent on the level of abstraction required to allow for effective problem solving, and shifts back and forth along the horizontal axis (between the visible and invisible structural dimensions) as the system is brought into alignment.

All four students of the case study reported on in this paper were externally assessed as capable of integrating the required knowledge for the diploma qualification. However, students L and T tend to articulate their understanding of systems based on more context-dependent practices, drawing on experiential knowledge, suggesting a form of ‘cumulative learning’ based on “students’ habituses rather than explicitly articulated procedures” (Maton 2009, 58). The ultimate system functioning at the level of innovation, however, required engagement in practices that emerged out of a particular context, but that needed to be elevated from that context in order to effect an innovative solution. Only students P and R were able to do so, and went on to complete the project independently and win the international competition. That students P and R were able to interpret the required knowledge in epistemic terms, and articulate this at a higher level of abstraction, suggests not only “the different orientations to meaning students bring with them to education” (Maton 2009, 55), but also the conceptual grasp of complex synthesis required for such an emerging region.

Conclusion

This paper set out to examine the knowledge integration practices of final year Mechatronics students at a University of Technology. The purpose of the research was to illuminate the nature of and the relationship between the *conceptual* and *contextual* aspects of an emerging multidisciplinary region, so as to inform curriculum design and qualification types. Drawing on the conceptual tools of Basil Bernstein and his followers, an analysis of the current curriculum revealed that it is derived from distinctly different knowledge structures, each of which has different implications for *conceptual* grasp. An adaptation of Karl Maton's concept of semantic gravity (2009), enabled the analysis of student problem-solving practice over time, and offered a lens through which to examine the relationship between different types of knowledge on which the students drew, as well as the degree of verticality in the student's actual practice regardless of the knowledge type. This analysis demonstrates that the two knowledge structure types operate symbiotically, suggesting a third form, a *dynamic bi-axial knowledge structure*.

What appeared clear from the curriculum analysis was the difference in weighting of the two types of knowledge structure as represented in the curriculum and as evidenced in practice. Practice in this region is predominantly based on horizontal knowledge structures as represented by both the mathematics and logic entailed in 'control systems'. This has implications for the assumption that physics forms such a fundamental part of the curriculum's epistemic foundation. Although the role and significance of physics itself is not in dispute, its underlying hierarchical knowledge structure is not the dominant way in which knowledge is built in this region. The findings from this study suggest that a more complex knowledge structure may characterise this emerging multidisciplinary region, requiring a complex praxis capability: the ability to appropriately access relevant theory from the core disciplines (the ‘know-why’) as well as procedural ‘know-how’, and to integrate these in a particular context of application.

The focus on successful student knowledge practice integration highlights principles that need to be taken into account in both curriculum design and pedagogy for the region. If the epistemic base is a *synthesis* of *separate* knowledge forms, then appropriate space and time needs to be accorded in the curriculum for the independent knowledge types, as well as spaces in which the relationship between the different *conceptual* and *contextual* forms of knowledge are made explicit. The synthesis does not necessarily emerge after independent exposure to the different types of knowledge, as assumed in a ‘collection type’ curriculum. It is in itself a third form: a complex and dynamic biaxial structure requiring a complex praxis capability. Our curricula need to accommodate this complex synthesis. The conceptualisation of multidisciplinarity as presented in this paper offers a framework through which to develop a much-needed coherent ‘relational idea’ (Bernstein 1975, 83) as the vertical ‘spine’ for such emerging regions, as well as a platform from which to review our curricula and pedagogic practice.

References

Bailey McEwan, M. 2009. Difficulties of mechanical engineering students in developing integrated knowledge for the cross-discipline of Mechatronics: A conceptual investigation. MPhil diss., Johannesburg: University of the Witwatersrand.

Barr, M. 2011. *Introduction to pulse width modulation.* http://www.netrino.com/Embedded-Systems/How-To/PWM-Pulse-Width-Modulation (accessed July 29, 2011).

Bernstein, B. 2000. *Pedagogy, symbolic control and identity: Theory, research, critique, rev. edn.* London: Rowman & Littlefield.

—. 1975. *Class, codes & control.* Vol. III. London: Routledge.

—. 1996. *Pedagogy, symbolic control and identity: Theory, research, critique.* London: Taylor & Francis.

Bishop, R. H., ed. 2002. *The Mechatronics Handbook.* Media Fire. http://www.mediafire.com/?ese8srfvtkudtve (accessed December 15, 2010).

Maton, K. 2009. Cumulative and segmented learning: exploring the role of curriculum structures in knowledge building. *British Journal of Sociology of Education.* 30 (1): 43-57.

Maton, K, and J. Muller. 2006. A sociology for the transmission of knowledges. *Legitimation Code Theory.* http://www.KarlMaton.com (accessed December 10, 2010).

Mechatronics Education Forum of Southern Africa. 2011. *2nd General meeting minutes.* Cape Town.

Muller, J. 2008. In search of coherence: A conceptual guide to curriculum planning for comprehensive universities. Report prepared for the SANTED Project, Centre for Education Policy Development. University of Cape Town.

Shooter, S., and M. McNeil. 2002. Interdisciplinary collaborative learning in Mechatronics at Bucknell University. *Journal of Engineering Education*. 91 (3): 339-344.

Wright, J. 1999. The debate over which PLC programming language is state-of-the-art. http://atmae.org/jit/Articles/wrig0899.pdf (accessed June 26, 2011).

Young, M, and J. Muller. 2007. Truth and truthfulness in the sociology of education. *Theory and Research in Education* 5 (2): 173-201.