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Integrating multidisciplinary engineering knowledge in a final year technical university diploma programme: an analysis of student praxis

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This work has not been previously submitted in whole, or in part, for the award of any degree. It is my own work. Each significant contribution to, and quotation in, this dissertation from the work, or works, of other people has been attributed, and has been cited and referenced using the APA convention.

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Glossary of technical terms[1]

Fluid mechanics	"the study of fluids and the forces on them. (Fluids include liquids, gases, and plasmas.)".
Logic	"A branch of philosophy and mathematics that deals with the formal principles, methods and criteria of validity of inference, reasoning and knowledge".
Logic programming	"The study or implementation of computer programs capable of discovering or checking proofs of formal expressions or segments". The user writes a database of 'facts' and 'rules', which are collectively known as 'clauses'. "The user supplies a 'goal' which the system attempts to prove using 'resolution' or 'backward chaining'. This involves matching the current goal against each fact or the left hand side of each rule using 'unification'. If the goal matches a fact, the goal succeeds; if it matches a rule then the process recurses, taking each sub-goal on the right hand side of the rule as the current goal. If all sub-goals succeed then the rule succeeds".
Mechatronics	The combination of "Mechanical engineering, Electronic engineering, Computer engineering, Software engineering, Control engineering", as used in the design and development of new manufacturing techniques
Microcontroller	"A small computer on a single integrated circuit containing a processor core, memory, and programmable input/output peripherals"
Potentiometer	"a device for measuring electromotive force or potential difference by comparison with a known voltage"
PLC	Programmable Logic Controller: A device used to automate monitoring and control of industrial plants.
PWM	Pulse-width modulation (PWM), or pulse-duration modulation (PDM), is a commonly used technique for controlling power to inertial electrical devices, made practical by modern electronic power switches.
Torque	"something that produces or tends to produce torsion or rotation; the moment of a force or system of forces tending to cause rotation"

[1] All definitions supplied by Dictionary.com LLC (2011) http://dictionary.reference.com/browse/technology

Abstract

In order to determine two distinct engineering qualification levels for an existing University of Technology (UoT) programme, empirical evidence based on the current diploma is necessary to inform decisions as to qualification-appropriate curriculum design. This evidence needs to shed light on the nature of and the relationship between the *contextual* and *conceptual* elements underpinning a multidisciplinary engineering curriculum. The design of such curricula at UoTs is made complex by the existence of multiple stakeholders, multiple disciplines, an absence of a coherent regional theory, and apparently dichotomous knowledge structures. These factors have meant an increasing focus on contextual application, which, in theory, could result in decreasing opportunities to develop the conceptual disciplinary grasp required for a dynamic, emerging region at the forefront of technological innovation.

These complexities have manifested themselves in widespread evidence of the difficulty of multidisciplinary knowledge integration. This research takes the approach that despite the apparent epistemological and ontological weakness of the region, practice is thriving. A predominantly single case study approach from a theoretically deductive position is employed, but within a methodologically inductive and pluralist framework which draws on conceptual elements from the empirical setting. Through an examination of final year diploma student practice as manifest in texts, interviews and observation, the research addresses the question of how multidisciplinary knowledge is integrated by the students, and what this reveals about the nature of such knowledge. There appears to be evidence of an alternative form of conceptuality in the emergence of a pattern of knowledge integration that moves along two axes simultaneously, through both hierarchical and horizontal knowledge structures, as well as at varying levels of context-dependency.

In focusing on final year student practice, using the theories and analytical tools of Basil Bernstein and Karl Maton, I hope to shed light on the nature of knowledge underpinning the region so as to inform decisions regarding appropriate curriculum design and qualification levels.

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Chapter 1. Introduction

1.1 Background: Engineering curriculum design complexity

In Higher Education (HE) the curricula of emerging multidisciplinary engineering regions are typically constructed by drawing from pure disciplines (such as physics and mathematics), ‘regional’ sub-disciplines (such as Mechanics or Electronics), and ‘subject areas’ specifically created to allow for the integration and application of knowledge specific to the emerging region. The weighting and nature of these elements that constitute the curriculum are dependent on the purpose of the qualification. The higher the level of the qualification in engineering, the more likely the focus is to be on mathematical and physics-based theoretical fundamentals, with integration/application by way of theoretical simulation. Such curricula have what Muller terms greater *conceptual coherence* (2008). The lower the qualification, the more likely the focus is to be on application in a practical environment, and a curriculum designed around *contextual coherence*. These two curriculum types are currently assumed to represent a potential coherence continuum underpinning the general, professional or vocational purposes of qualifications (Muller, 2008). Decisions as to curriculum content, conceptual/contextual curriculum coherence, qualification purpose and exit level outcomes are informed by key stakeholders including the State, accreditation bodies, professional associations, producers of knowledge and academics. These all play a role in what Bernstein (2000) has termed ‘recontextualisation’: the delocation, transformation and relocation of knowledge as part of pedagogic discourse.

In the case of multidisciplinary engineering, consensus as to curricular decisions and requisite outcomes is complicated by a number of factors. New knowledge tends to be generated by industry/research specialists from the sub-disciplines which constitute the emerging region, and the academics who help to construct and teach curricula, similarly, tend to hail from various sub-disciplines. Secondly, the curricula for new regions emerge in ‘cut ‘n paste’ fashion, drawing subject content from a range of disciplines as suits the purpose of application and qualification, and not necessarily in terms of a coherent ‘regional’ theory, or an explicit “relational idea” (Bernstein B., 1975, p. 83). Thirdly, in technologically-driven multidisciplinary regions, development is too rapid to allow time for the recontextualisation of materials by academics, and so HE curricula depend on industry-generated texts for the application of newly produced technological knowledge. This implies not only a shift in power from the academy to industry, but also a shift from the potentially conceptual to contextually-dependent application of knowledge.

1.2 HEQF and Recurriculation: The Mechatronics Program

At the forefront of emerging multidisciplinary engineering regions, ‘Mechatronics’ is a synthesis of mechanical, electrical and control system (computer-based) engineering, employing the latest in automation innovations generated by industrial research and development. It is a dynamic region in which “despite continuing efforts to define mechatronics [...] and to develop a standard mechatronics curriculum, a consensus opinion on an all-encompassing description of 'what is mechatronics' eludes us" (Bishop, 2002, p. 38). Evidence of this is the fact that it rarely exists as a region in its own right, falling in some faculties under either Mechanical, Electrical, Aeronautical or Industrial Engineering departments. In most cases it is offered as a specialisation route after two academic years in the Mechanical or Electrical Engineering Bachelor's qualification.

Currently, HE institutions in South Africa are in the process of designing new and redesigning existing qualifications and curricula in order to meet the prescriptions of the Higher Education Qualifications Framework (HEQF) (2007). The site of the research presented here is the Mechatronics Program (sic) at a University of Technology (UoT). In its fifth year under the Mechanical Engineering department, this diploma programme is intended to be submitted as an independent qualification, at two potential levels: a Diploma and a Bachelor of Engineering Technology. The recurriculation[2] process entails first and foremost establishing an identity independent of the Mechanical Engineering department, as well as designing a responsive curriculum to meet the standards established by the Engineering Standards Generating Body. The generic standard for a diploma describes a *Professional Engineering Technician* as being "characterized by the ability to apply proven, commonly understood techniques, procedures, practices and codes to solve *well-defined* problems" (Diploma in Engineering, 2008), whereas a *Professional Engineering Technologist* (BEngTech) engages with more *broadly defined* problems. These two qualification descriptors imply a differentiation in approach to curriculum, pedagogy and practice, particularly with regard to the *conceptual* and *contextual* focus.

Two years of observation and data collection on final year Mechatronics students on the programme have revealed notably varied performance in relation to 'well-defined' problem-solving. On the one hand, there is increasing local and international evidence of students' difficulties in integrating multidisciplinary knowledge in application in this emerging region. On the other hand, assessment processes have revealed that a significant number of the Mechatronics students at the research site are working beyond the confines of 'well-defined' problem-solving. This suggests that the current diploma programme is straddling the two potential qualifications. In order to recurriculate two clearly defined qualifications, empirical evidence based on the current diploma is necessary to inform decisions as to qualification-appropriate curriculum design.

1.3 Aim of the research

Epistemologically[3], a Mechatronics curriculum is comprised of a range of subjects that are fundamentally different in nature and which require very different learning and application practices. In curriculum documentation these are often listed generically under 'Engineering

[2] In the South African context the term 'recurriculation' is used to mean the redesign or restructuring of the curriculum.

[3] Bernstein defines curriculum "in terms of the principle by which certain periods of time and their contents are brought into a special relationship with each other" (1975, pp. 79-80). Ron Barnett adds a further dimension to curriculum by separating the "epistemological (knowing), praxis (action) and ontological (self-identity) elements" (2000, p. 258). I will not be engaging in contemporary debate about the definition of knowledge at this stage (Balarin, 2008, Young & Muller, 2007) and am using the term 'epistemology' to describe the underlying differentiated categorisations of codified forms of knowledge (contents) underpinning a curriculum.

Sciences', giving little indication as to what their knowledge base might be unless one reviews the actual syllabi. As part of this research project I conducted an examination of the current curriculum and discovered that its epistemological roots lie across the traditional Humanities/Sciences divide and that its field of praxis[4] lies outside the boundaries of the traditional university. However, the current curriculum is highly integrated in some areas and repeated recontextualisation processes have rendered these epistemological roots blurry. The implications of the straddling of traditional boundaries may not be evident to the stakeholders who play a role in curriculum design. The increasing evidence of the difficulty in integrating knowledge in this region may lie in the fact that curriculum developers have underestimated three factors:

- the dichotomous nature of the underlying knowledge structures
- the disjuncture between the assumed theoretical foundations and the field of praxis
- the nature and degree of conceptuality required to integrate Mechatronics knowledge

Without a strong disciplinary core, "the knowledge base [in a region] will be weak on 'know-why', the knowledge condition for exploring alternatives systematically and generating innovation" (Becher & Parry, 2005 in Muller, 2008, p. 18). Given the problem-solving focus of this region and its status as a site of innovation, the kind "that the global economy prizes most at all levels of the division of labour" (Muller, 2008, p. 25), 'know-why' is crucial and dependent on conceptual knowledge, the (vertical) spine of a discipline. In Mechatronics, however, there is currently no apparent integrating conceptual spine. The notion of 'conceptuality', in engineering, is trapped within a physics-based paradigm, and together with mathematics, these are assumed to form the disciplinary core of most engineering qualifications. The first two years of the current Mechatronics curriculum is testimony to this belief. However, the majority of 'subject' areas in Mechatronics in practice are in fact non-physics-based. They are 'trial-and-error type' applications of control technologies in particular contexts where procedures may be dictated by multiple variables, each of which may have a particular logic (organising principle). This has led to what would be termed a very contextual curriculum, particularly in the third year. A predominantly contextual curriculum would constrain the qualification potential to a lower order, assuming one accepts the proposed SANTED[5] conceptual/contextual curriculum typologies (Shay, et al., 2011). However, in order to function in this region, what is required is the ability to rapidly acquire the new knowledge (and associated practices) produced by research and industry specialists, particularly those pertaining to technological innovations. The evidence that some students at the diploma level are doing this without explicit exposure to a curriculated regional form of disciplinary conceptuality (an overarching, integrating principle, such as, for example, a theory of systems) suggests there must be some kind of conceptual grasp. I suspect that despite their apparent contextual nature,

4 By 'praxis' I mean to suggest 'theory-informed practice'. I will be using the term in more theoretical contexts, as opposed to the term 'practice' to refer to actual instances or processes involved in practical application.
5 The South Africa Norway Tertiary Education Development Programme, a Centre for Education Policy Development (CEPD) project to assist in the transformation of HE in SA.

emerging multidisciplinary regions require a kind of conceptuality not accommodated or acknowledged by current curriculum/knowledge typologies.

On the other hand, many students fare well in the initial traditionally conceptual subjects (physics-based 'Mechanics', for example), but fail to apply integrated knowledge in the field of practice. This furthered my hypothesis that the conceptual physics-based paradigm shaping the core disciplinary subjects may act as a constraint on practice. I was alerted to the disjuncture between the assumed theoretical foundations (conceptual) and the field of praxis (contextual) by a written student submission in March 2011 which stated that it "feels like the previous t[w]o years of studying is a waste compared to all the things I have learnt in the past 7 weeks". This statement from an academically successful student, together with the observation that Mechatronics students working in a self-managed simulated professional environment may be integrating knowledge in multiple ways in multiple contexts, with varying degrees of success, led me to shift my focus: from forms of knowledge to praxis.

Given the lack of disciplinary consensus as to the knowledge base of the region and the repeatedly recontextualised[6] current curriculum, it is my intention through an examination of student praxis to attempt to determine whether or not these students are in fact integrating knowledge, and if so, to find out *what kind* of knowledge, *how* they are doing so, and what degree of *conceptuality* is evident. If, as I suspect, some are tacitly or even explicitly working with a range of knowledge forms traditionally assumed to lie in separate categories of knowledge, then this emerging region represents a space across great epistemic divides. This may have implications not only for curriculum design and pedagogy in the region itself, but also for other rapidly evolving non-engineering multidisciplinary regions.

1.4 Research questions

The research question is situated within the broader problematic of 21st century vocational/professional multidisciplinary curriculum design. The original focus was to have been on final year Mechatronics students' practical experience of the existing curriculum as manifest in academic and industrial recontextualised texts encountered during the semester prior to Workplace Learning. I had assumed, firstly, that there would be texts and, secondly, that these would represent a synthesis of the preceding two years of academic instruction, an extension of theory into practice. Upon examination, however, it quickly became evident that the only available texts in the final year are little more than procedural, object-orientated instructions pertaining to specific technologies, with no indication of the type of knowledge required, and certainly no evident degree of conceptuality. The fact that several students admitted to never reading these texts because "we

[6] An example would be the process by which elements of the Mechanical Engineering curriculum (already a recontextualisation of physics and mathematics) are combined with elements from the Computer Engineering curriculum (for example, programming syntax) and added to Technical Drawing (geometry and visual modelling) to create a subject called Computer Aided Manufacturing (CAM).

know what to do”[7] piqued my interest considerably and led to a decision to focus on *what* exactly it is that they *are* doing and *how* they are doing it.

The primary research question is:

How do final year Mechatronics engineering diploma students integrate and apply multidisciplinary knowledge, and what might the process reveal about the nature of the knowledge itself and the enabling conditions for integration?

The following sub-questions arise out of the above formulation:

- What does ‘integrate and apply knowledge’ mean in this context?
- What kind of knowledge is available to the student and how does he/she perceive this?
- What are the procedures the student follows in applying this knowledge?
- What enables the student to integrate the knowledge effectively?
- What does the student’s integration process tell us about the way this kind of knowledge works?

The intention of these questions is ultimately to illuminate the three ‘hypotheses’ I previously raised for further investigation:

- Unrecognised dichotomous knowledge structures underpinning the emerging region
- Disjuncture between assumed theoretical foundations and praxis
- Type of conceptuality that knowledge integration in such a region requires

In looking at *how* students work with *what kind* of knowledge, I am fundamentally interested in how the dichotomous underlying knowledge structures are manifest in practice, and whether or not evidence of this dichotomy reveals the disjuncture between what is assumed to be the conceptual theoretical basis of the region and what form of conceptuality actually emerges in practice. It is the presence and form of conceptuality that should determine the potential qualification level. In the case of successful integration of relevant knowledge, I am interested in whether or not a new ‘regional logic’ emerges or whether the different forms of logic of the originating sub-disciplines somehow dictate how students work in practice, and what role the learning paradigm underpinning the semester plays. Evidence of a limited range of knowledge that is context-bound may also speak to the three hypotheses.

1.5 Dissertation outline

I will begin with a literature review sketching available empirical evidence on the problems of knowledge integration in this region as well as the complexity of multidisciplinary engineering

[7] This emerged in several interviews with students both within and beyond the case study, where I would ask questions such as “Where are the instructions for the station?” and many would respond that the lecturer had “explained what we must do” or they had simply asked the previous group on a particular ‘station’. Where there were texts available (subject guide), interviewees often self-consciously admitted to not having read these.

curriculum design. I will be drawing on the literature to argue that there are multiple 'types' of knowledge implied in this region, and that the current notion of conceptual/contextual curricula determining qualification levels is possibly limited. Drawing extensively on the work of Basil Bernstein (1975, 1977, 1990, 1996, 2000), in chapter three I intend to develop a conceptual framework describing the nature of multidisciplinary engineering knowledge, specifically that of Mechatronics. In order to answer the research question, I draw on the work of Karl Maton (2009), in conjunction with Muller (2006, 2007) and Moore (2010), particularly in the development of an external language of description, based on the principles of *semantic gravity* (2009). Chapter four introduces the case study and motivates the underlying methodological and paradigmatic pluralism. An analysis of the practices of a particular group of students from the January 2011 third year cohort follows in chapter five, extensively supported by graphically interpreted data. A discussion on the findings highlights the implications for curriculum and qualification levels of integrating dichotomous knowledge structures and discourses.

Chapter 2. Literature Review

2.1 Introduction to the literature

This research is situated within the general theoretical field of sociology of education, with a focus on knowledge and curriculum. A number of works from key theorists and researchers in this field adopt a fairly linear approach, moving from knowledge to curriculum, then on to pedagogy and practice. The reason for this direction in knowledge analysis appears to be one of academic certainty as to what constitutes the knowledge foundation of a discipline or region. The overriding concern of many sociological theorists in the context of curriculum analysis in recent decades has become the extent to which the knowledge is recontextualised by powerful stakeholders so as to perpetuate or entrench social power relations. My proposition, however, is that multidisciplinary engineering of the twenty first century is epistemologically ill-defined and ontologically weaker than its traditional engineering counterparts. This is as a result, firstly, of a lack of consensus as to what precisely constitutes a dynamic, emerging region. Secondly, the multiple potential epistemic and social orientations framing the contributions of stakeholders responsible for curricular decisions have a profound influence on a region's potential ontological strength. The status of the region in the global economy, however, suggests that despite apparent epistemological and ontological weakness, the field of practice is thriving. It is the curriculum that links these dimensions, and since the purpose of this research is to inform the curriculum, I have elected to reverse the direction of knowledge analysis by focusing on praxis as a means to potentially illuminate the epistemological foundations.

I will begin by situating the research question in the context of recent empirical studies highlighting the problems of multidisciplinary knowledge integration in practice, with a specific focus on the emerging region that constitutes the basis for this research: Mechatronics. I will then place this in the broader context of vocational/professional curriculum development for a 'supercomplex' world (Barnett R. , 2000), where the focus has shifted away from epistemology. The highly contextual nature of qualifications such as the Mechatronics diploma may act as a potential constraint to the conceptual grasp necessary to function in this dynamic region. This has implications for the level of qualifications. Chapter two ends with a brief examination of the current conceptual/contextual curriculum coherence discussion.

2.2 Empirical research in the field

A key work which has informed my research is that of Dr Bailey McEwan, entitled "Difficulties of Mechanical Engineering students in developing integrated knowledge for the cross-discipline of Mechatronics" (2009). His research site is a traditional university in South Africa, where the 'Mechatronics' component is only introduced in the third year of study for a Professional Bachelor's after two formative years in either Mechanical or Electrical engineering. The research focuses on establishing the necessity for connecting mechanical and electrical engineering knowledge, and

Bailey McEwan effectively uses a Bernsteinian analytical framework to determine that these students are in fact learning what should be the 'hierarchical' physics-based knowledge in a 'horizontal' fashion, as a result of a collection-type curriculum. Bernstein, to whom I return later, conceptualises knowledge structures as follows: "Hierarchical knowledge structures develop through new knowledge integrating and subsuming previous knowledge, whereas horizontal knowledge structures develop through adding on another segmented approach or topic area" (Maton K. , 2009, p. 45). When a curriculum is a collection-type, this means the knowledge of one area is kept distinct from that of another. Multidisciplinary curricula tend to manifest in this form as a result of drawing knowledge from different disciplines. Of concern in Bailey McEwan's work is that he explores theories of knowledge-building, and suggests the use of bond graphs, a conceptual tool, to "reveal the common governing principles of different physical systems by representing them as interconnected components handling various forms of energy..." (Bailey McEwan, 2009, p. iii). The focus of these 'systems' are those pertaining to mechanical and electrical systems, where the common underlying principles are physics-based.

The research is significant in that it highlights widespread problems related to the integration of multidisciplinary knowledge. However, there are a number of differences in relation to my research, not the least of which is the difference between traditional university professional degrees and vocational/ professional UoT diplomas with respect to the conceptual/contextual curricular focus. Of primary concern, however, is that the problem of integration in Bailey McEwan's research is predominantly framed by the principles of physics underlying *mechanical* and *electrical* engineering[8]. The dominance of these two established regional forms of engineering is evident in Mechatronics programmes globally, in that they are generally seen as an extension of either one or the other and so tend to reside in either of these departments. It is for this reason that physics and mathematics appear to be unproblematically regarded as the epistemological basis of Mechatronics Engineering.

Lyshevski, of Purdue University, Indianapolis, shifts the focus to a different dimension in the problem of knowledge integration: "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" (Bishop, 2002, p. 68). This suggests there may be a difference between programming and engineering 'skills', a difference further illuminated by research findings into collaborative pedagogy at Bucknell University (Shooter & McNeil, 2002). Here, 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. What these accounts suggest is that Mechatronics is more than an extension of mechanical and electrical engineering disciplines.

[8] Although Bailey McEwan does concede that not all 'languages' should "necessarily be mutually translatable, such as solid mechanics on the one hand, and computing and software development on the other" (2009, p. 50).

The newly-established Mechatronics Education Forum of Southern Africa (MEFSA) recently agreed on the necessity of establishing an independent identity so as to dislodge the emerging region from the electrical/mechanical stranglehold, and offered an alternative definition:

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

This definition alludes not only to the simultaneity and dynamism of 21st century complex systems, but highlights a key knowledge form that is not physics-based: that of computer control. This essentially falls under Computer Engineering, the third originating disciplinary region. Together with Mechanical and Electrical Engineering, these three sub-regions constitute Mechatronics Engineering, and this combination has implications for knowledge integration that need to be considered in curriculum design. However, the curriculum first needs to be situated "amid the wider and even global context" (Barnett R. , 2000, p. 257).

2.3 Supercomplexity and curriculum

The MEFSA definition and empirical evidence on the problems of knowledge integration (Bailey McEwan, 2009; Bishop, 2002; Shooter & McNeil, 2002) firmly establishes Mechatronics as potentially epistemologically complex. At a praxis level, the implications for curricula are similarly complex. Vocational/professional engineering curricula, the focus of powerful stakeholders wishing to alleviate the national skills shortage, are developed according to guidelines established by professional associations, in this case the Engineering Council of South Africa (ECSA). Adherence to these guidelines, based on the input of industry, assures accreditation of qualifications. What this means is that vocational/professional qualifications, particularly at the UoTs, exhibit the "closer relationships with wider stakeholders" which, Barnett (2000) argues, following Lyotard (1984), have added to a general "performative slide" as a result of "pragmatic interests directed to problems in the world" (Barnett R. , 2000, p. 260). In essence, students today are expected to demonstrate ('perform') their understanding, their 'skills', and processes, in tangible outputs: reflective logs to demonstrate self-monitoring; formal presentations to demonstrate problem-solving, routines, and generic professional practice (communication and teamwork abilities); and the demonstration of ICT expertise to enable life-long learning. These elements of performativity are the assessment focus of half the required exit level outcomes for a diploma (Appendix A), and add yet another layer of complexity to multidisciplinary vocational/professional curriculum design, as they represent generic capabilities far removed from disciplinary knowledge.

The first five of the exit level outcomes, however, are concerned with evidence of discipline-specific application of knowledge. This is the type of knowledge which Michael Barnett terms situated knowledge, "associated with particular job tasks... frequently tacit [and] hard to codify" (2006, p. 146), and facilitated by the Work Integrated Learning (WIL) components of current UoT diploma programmes. The relationship between situated and disciplinary knowledge, however, is problematic, given that the former "is often trapped within its context of application" and the latter "generally aspires to some degree of context-independence" (ibid.). What should be clear by now is that UoT engineering diploma qualifications are predominantly contextual and performatively orientated, factors which may not only appear to threaten the traditional notion of *conceptual* disciplinary grasp, but which are assessed in a manner that may not accommodate or acknowledge alternative notions of conceptuality, given that the assessors hail from sub-disciplines and the evidence of application of "scientific and engineering knowledge" (Exit Level Outcome 2) often depends on the practical manifestation in the form of a final physical 'project' in a particular context.

Muller (2008) differentiates between the *conceptual* and *contextual* poles of curriculum logics by focussing on the *purpose* of a qualification. He has broadly outlined four potential occupational fields and describes four qualification routes (on a conceptual/contextual curriculum coherence continuum), where route one represents traditional academic and "4th generation professions", and route four "particular occupations" (2008, p. 29). He describes two potential qualification routes for engineering: route three applies to pre-Bachelors occupations, with a more *contextually-coherent* curriculum, and practical knowledge with applied theory. Route two is for professional engineers, with a more *conceptually-coherent* curriculum, applied theory and practical experience. The current Mechatronics diploma curriculum resides in route three. However, having established that "engineering overlaps three and two", Muller places "ICT and other fourth generation professions" between the second (professional) and first (academic) routes (2008, p. 31). The reason for this is that Information Communication Technologies (ICTs) are the foundation in the 21st century for innovation, and "innovation relies on conceptual knowledge" (ibid., p. 26). As described in the empirical research section, Mechatronics draws its knowledge from three engineering regions. Two of these, Mechanical and Electrical, have two potential qualification routes as described above. Computer or Control Engineering, however, falls under ICTs, which lie between the two more conceptually-orientated traditional academic and professional qualification routes. Given the complexity and dynamism of the emerging multidisciplinary region, and its dependence on the implementation of innovative technologies, it is the nature of and the relationship between the 'contextual and conceptual' knowledge appropriate to this region that this research project wishes to address.

Chapter 3. Conceptual framework

3.1 Introduction to the conceptual framework

Karl Maton (2009) describes the integration and subsumption of previous knowledge as ‘cumulative learning’, the aim of which is to enable the acquisition of “higher-order principles of knowledge”, and transfer that is not context-specific (p. 44). This form of knowledge-building could be termed *conceptual*. Maton has developed the theories of educational sociologist, Basil Bernstein, who was concerned with establishing a theoretical framework through which to analyse the production and reproduction of knowledge. In order to address the research question as to *how* third year multidisciplinary engineering students on a diploma programme are integrating *what kind* of knowledge, I am fundamentally interested in the relationship between the contextual and conceptual, and “the ways in which the structuring of knowledge itself works to shape social practices, identity, relation and consciousness” (Maton & Muller, 2006, p. 21).

3.2 Discourses and knowledge structures

“Bernstein’s work[9] represents one of the most sustained and powerful attempts to investigate significant issues in the sociology of education” and “provided a systematic analysis of codes, pedagogic discourse and practice and their relationship to symbolic control and identity” (Sadovnik, 2001, p. 696). “Code refers to the principles that regulate meaning systems” (Hoadley, 2006, p. 3). Bernstein theorises several ‘codes’, from the description of curricula as *collection* or *integrated* (1975) to the *restricted* and *elaborated* codes that characterise both context-dependent and context-independent meanings respectively as well as orientations to meaning. Code theory was developed to describe how “education specializes consciousness” (Hoadley, 2006, p. 5). Bernstein regards “pedagogic practice as a fundamental social context through which cultural reproduction-production takes place” (1996, p. 3). Pedagogic discourse is a “recontextualising principle... which selectively appropriates, relocates, refocuses and relates other discourses to constitute its own order” (Bernstein B. , 2000, p. 33). It is “a rule which embeds two discourses” (ibid., p. 31), Instructional Discourse (ID), which regulates the creation of skills and the rules pertaining to the relations between these, and Regulative Discourse (RD), which are rules of social order referring to hierarchical pedagogic relations and “expectations about conduct, character and manner” (2000, p. 13). The recontextualising principle creates ‘fields’ and “agents with recontextualising functions” (ibid., p. 33). Bernstein distinguished between two key recontextualising fields, the official (ORF) and the pedagogic (PRF). The Field of Recontextualisation (FoR), governed by *recontextualising* rules, is situated between the Field of Production (FoP) and the Field of Reproduction (FoRep), which are respectively governed by *distributive* and *evaluative* rules. These sets of rules effectively regulate and legitimise educational knowledge and its access.

[9] The constraints of this minor dissertation are such that a more comprehensive overview of Bernsteinian theory is impossible. I have elected to highlight certain key features on which I will draw as the argument develops.

The focus of this research study is primarily the analysis of the underlying structuring principles of complex multidisciplinary educational knowledge as applied by final year students in the Field of Reproduction. The context is one that allows for greater student agency as there is no explicit pedagogic relationship in relation to the epistemic content with which they engage in the period during which the research study takes place.

3.2.1 Horizontal discourse

Bernstein distinguished first of all between *vertical* and *horizontal* discourses, with the former being "specialised symbolic structures of explicit knowledge" (such as in education) and the latter context-specific and -dependent everyday knowledge embedded in on-going practices. Horizontal discourse is segmentally organised, contradictory across contexts, and "directed towards acquiring a common competence rather than a graded performance" (2000, p. 159). It evolves in different ways in different communities based on how the "culture segments and specialises activities and practices", and "entails a set of strategies [...] for maximising encounters with persons and habitats" (ibid., p. 157). Bernstein describes horizontal discourse as 'everyday knowledge', citing Habermas' term of "life world" (ibid., p. 155). He uses examples such as learning to tie one's shoe laces, using the lavatory, 'addressing different individuals' and 'using a telephone'. These practices are acquired through modelling by "the family, peer group or local community" (ibid., p. 159). Each individual develops a *repertoire*, "a set of strategies" that enables the individual to function in different social or practical contexts. "Any one individual may build up an extensive repertoire of strategies which can be varied according to the contingencies of the context or segment" (ibid.). Bernstein uses the term *reservoir* to refer to the total sets of repertoires in a community as a whole.

I would like to suggest that Bernstein's description of the acquisition of horizontal discourse as the realisation of practices associated with a particular "view of cultural realities" (ibid., p. 165) could be applicable to the non-disciplinary 'discourse practices' with which students in HE are expected to engage. Subjects such as Communication Skills and Professional Practice, common to vocational/professional curricula, are precisely about the development of oral *and* written *repertoires* that are context-dependent and which enable the individual to engage meaningfully with others in particular professional contexts[10]. That some of these forms of horizontal discourse have been pedagogised (and thus shifted to vertical discourse) as opposed to merely being inculcated as part of a tacit induction into practices modelled by 'community experts' is perhaps testimony to the equity and access thrust in HE which recognises differential prior access opportunities. This would imply the student in HE is far closer to the juncture between the traditional preserve of educational, vertical discourse, and that of the everyday, horizontal discourse.

[10] These types of practices are the basis of the non-disciplinary Exit Level Outcomes (6 – 10), and are currently referred to as generic skills or Graduate Attributes.

3.2.2 Vertical discourse

Vertical discourse consists of two forms. Hierarchical knowledge "attempts to create very general propositions and theories, which integrate knowledge at lower levels" (Bernstein B. , 2000, p. 161) and is characterised by ever increasing abstraction. The 'internal characteristics' that generate progress in knowledge with a hierarchical structure, such as in the case of physics, are what Young and Muller describe as a theory-integrating form of 'verticality' (2007, p. 189). 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 B. , 2000, p. 161). Each of these specialised languages, such as those of Sociology on the one hand, or mathematics on the other hand, has its own criteria for legitimate texts. When a new language is introduced, it does not subsume the elements of any of the other specialised languages as in the case of hierarchical knowledge (although it may develop some of the ideas), but "offers the possibility of a fresh perspective, a new set of questions, a new set of connections, and an apparently new problematic, and most importantly a new set of speakers" (ibid.). The difference between horizontal knowledge structures can further be described in terms of 'grammaticality': "how theoretical statements deal with their empirical predicates" (Young & Muller, 2007, p. 188). Those horizontal knowledge structures "whose languages have an explicit conceptual syntax capable of relatively precise empirical descriptions" (Bernstein B. , 2000, p. 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 & Muller, 2007, p. 188).

3.2.3 Classification

Bernstein used the principle of classification to describe the degree to which knowledge categories are insulated from each other. The stronger the classification, the more unique a category's identity, voice, and "specialised rules of internal relations" (2000, p. 7). As an example of the classificatory principle, Bernstein takes us back to the mental and manual medieval organisation of knowledge. The former had two distinct orders: *the trivium* and *the quadrivium*, and the latter "was never integrated into formal public systems of knowledge and transmission" (Bernstein B. , 2000, p. 8). In attempting to narrow down the question for this research project, I returned to the medieval organisation of knowledge and made a remarkable discovery: The epistemological roots of the emerging region (Figure 1, p. 14) can be traced back to this original organisation of knowledge and straddle almost the entire range, with a curriculum designed around elements of both the trivium and quadrivium, and with student employment occurring in the 21st century equivalent of all of the original seven 'mechanical arts'. The seventeenth century saw the evolution of the mathematics and physics foundations of today's curriculum in "the age of the scientist and ... 'mechanical philosophy'" and firmly established differentiation between scientist, artisan and humanist (Muller, 2008, p. 4), based on the original differentiation of forms of knowledge. It is highly significant that Mechatronics overlaps all three.

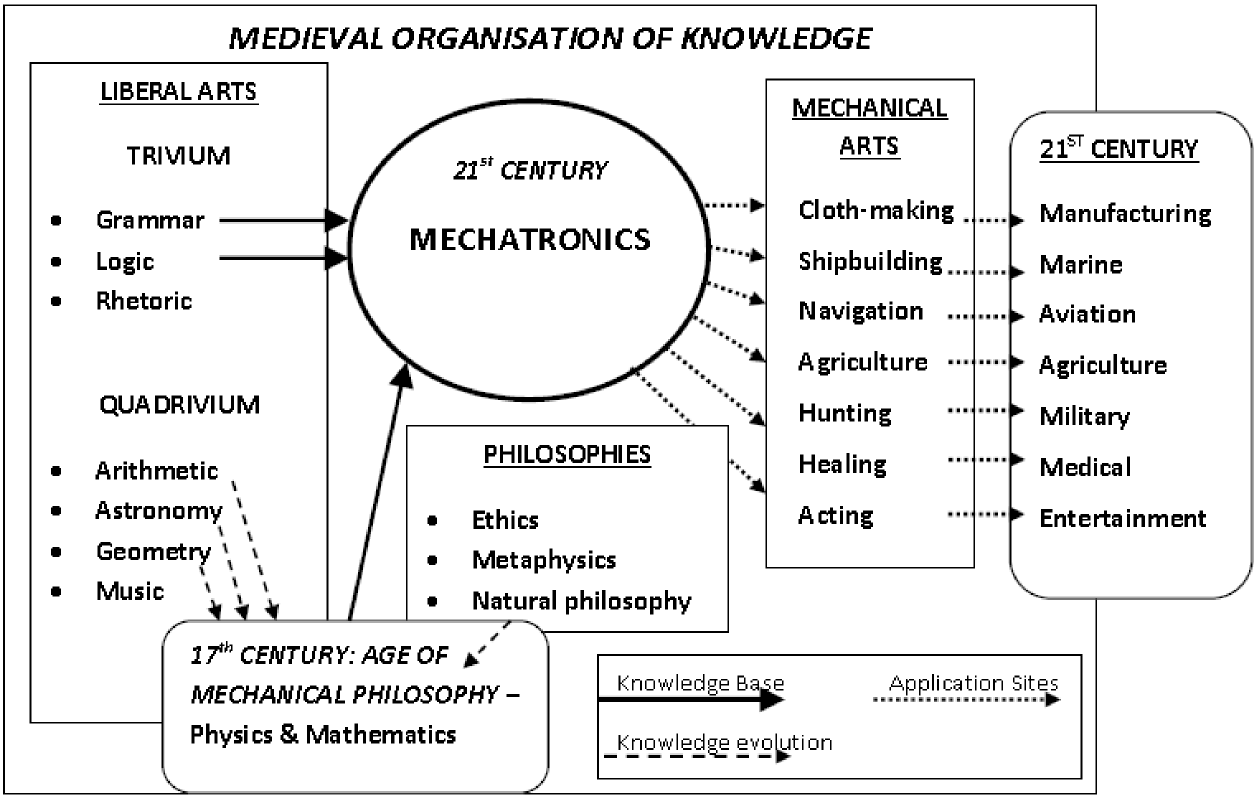

Figure 1 Mechatronics disciplinary roots

Bernstein further differentiates between vertical discourses as singulars and as regions. "A discourse as a singular is a discourse which has appropriated a space to give itself a unique name." Singulars, such as physics, have "very few external references other than in terms of themselves", whereas "a region is created by a recontextualising of singulars" (2000, p. 9). He states that "regions are the interface between the field of the production of knowledge and any field of practice" (ibid.) and that regionalisation leads to a weakening of classification. Whenever this happens, "there is space for ideology to play" (ibid.). As established in Chapter 2, the Mechatronics curriculum is shaped by the input of numerous potentially powerful stakeholders outside the academy. As a result, a curriculum may be progressively constituted according to particular epistemic and social orientations and not according to the logic of a "recontextualising principle" (ibid.) governing the region itself. "As the classification becomes weaker, we must have an understanding of the recontextualising principles which construct the new discourses" (ibid.). This 'understanding' can also be referred to as "consensus about the integrating idea" (Bernstein B. , 1975, p. 84), which, I believe, is currently not evident in the Mechatronics curricula I have examined.[11]

[11] It may be, however, that this 'integrating idea' becomes more explicit in pedagogic practice.

3.2.4 Knowledge structures in the Mechatronics curriculum

Whilst it is important to remember that “a knowledge structure is not necessarily a curriculum structure” (Maton & Muller, 2006, p. 27), the theoretical focus of this research project is the way in which the knowledge structures potentially manifest in practice despite multiple recontextualisations. Figure 2 illustrates an analysis of elements of the Mechatronics curriculum at the research site as illuminated by Bernstein’s classificatory principles. The knowledge structures are depicted at ninety degrees to each other and situated within vertical discourse, but with the generic learning areas represented as closer to horizontal discourse.

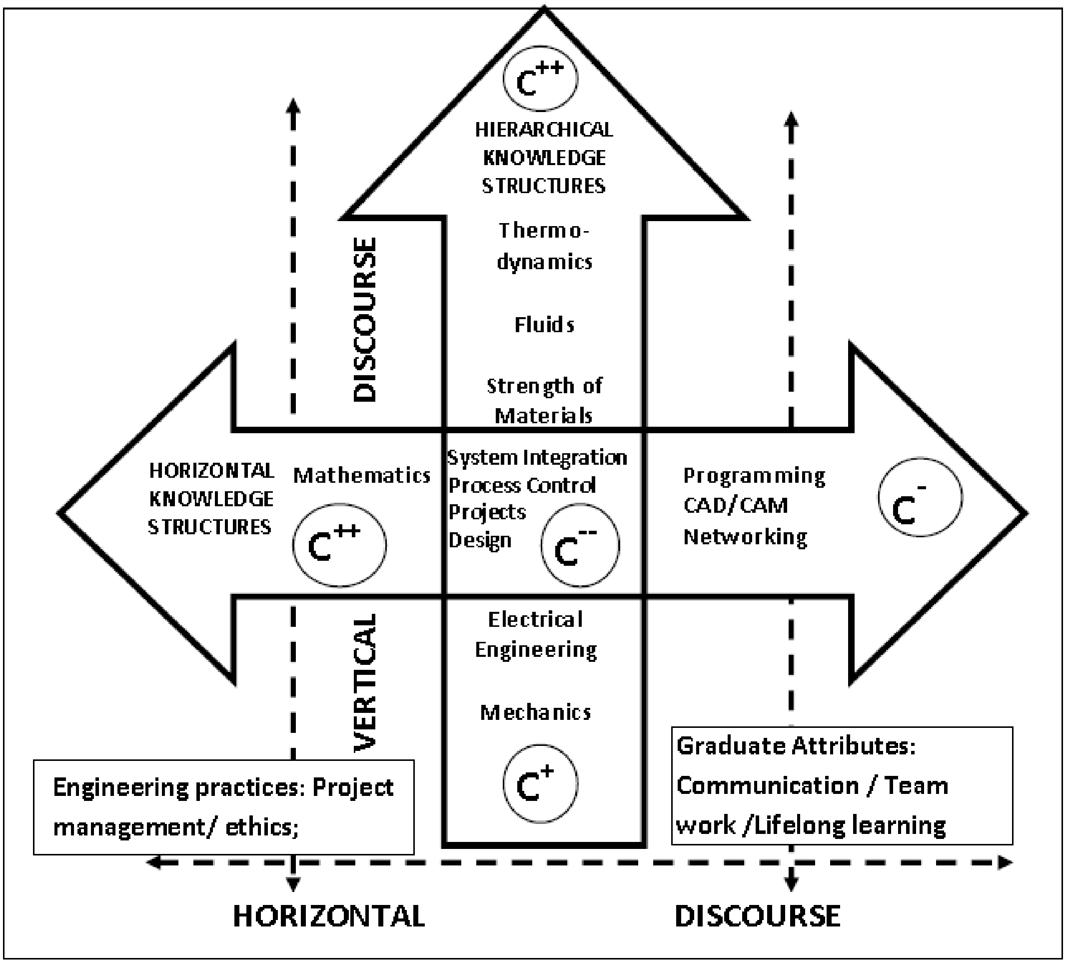

Figure 2 Mechatronics curriculum knowledge structures & classification

The strength of classification is not necessarily determined by the knowledge structure. It is the degree of boundary maintenance established by specialists in the field, what gives something its unique identity and separates it from other disciplines. Mathematics has a horizontal structure with a strong grammar, and a “form of verticality that is almost equivalent to that obtained in hierarchical knowledge structures” (Young & Muller, 2007, p. 188). It enjoys high status as a discipline and it is usual in engineering programmes for it to be taught fairly autonomously, as a subject in its own right, albeit as Applied Mathematics, which implies a context of application. Mathematics and the mechanical engineering subjects are strongly classified (C++) in the curriculum, the latter being as a result of the programme residing under the Mechanical Engineering department which has an established tradition in physics-based fundamentals. Half the current curriculum consists of mathematics and the physics-based mechanical and electrical engineering subjects, which are not only strongly classified (C++/C+), but also predominantly hierarchical in structure, requiring the specific selection and sequencing of content.

In contrast, Programming, which is weakly classified as it draws on the principles of language, logic and mathematics, is mainly applied to micro-controllers or Programmable Logic Controllers (PLCs). Programming has a horizontal knowledge structure[12] in that there is no general integrating proposition. Programming languages use descriptors such as *syntax, parsing, semantics*, and *etymology*, which indicate their close relationship to spoken/written languages. 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, 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, p. 2). This 'mixed modality', which has emerged in response to "the 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 B. , 2000, p. 166). In other words, these features emerge based on what people want in the real world. Programming 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.

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 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

[12] 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 & Muller, 2007, p. 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.

(employing ICTs). In addition to the relatively ‘applied’ exposure to these technologies, the curriculum includes subjects such as Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM), which are 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 is intended to manifest is Design (C^{--}).

Conceptually, hierarchically structured knowledge is highly dependent on sequencing and subsumptive progression. Horizontally structured knowledge, however, is the non-sequential “accumulation of *languages*” (Bernstein B. , 2000, p. 162). At the level of curriculum and pedagogy, this differentiation entails fundamentally different approaches to acquiring hierarchical and horizontal knowledge structures both independently and where they meet in ‘Design’, which has the added complexity of including generic practices more closely related to the principles of horizontal discourse. It is the integration of knowledge across these dichotomous structures that empirical evidence demonstrates as problematic. One cannot wish away this dichotomy, nor should one conflate the structural knowledge dichotomy with an assumed curricular conceptual/contextual dichotomy. These are fundamentally different kinds of knowledge, the grasp of which in both cases may occur through varying degrees of context-dependency.

3.3 Legitimation Code Theory

Legitimation Code Theory (LCT) “views the practices and beliefs of actors as embodying competing claims to legitimacy, or messages as to what should be considered the dominant basis of achievement within a social field of practice” (Maton K. , 2009, p. 45). Maton has developed a coding scheme to “help excavate the underlying principles generating forms of knowledge” (ibid., p. 46) according to the strength of the epistemic relation (ER) to the knowledge structure and the social relation (SR) to the knower structure. He suggests “hierarchical knowledge structures are underpinned by knowledge codes, and horizontal knowledge structures are typically generated by knower codes” (ibid.). LCT represents the foundation of an approach to the analysis of knowledge, knowers and practice that moves away from dichotomous absolutes to the principle of relative strengths along various continua.

3.3.1 Semantic Gravity

In an attempt “to explore the potential of educational knowledge structures to enable or constrain cumulative learning” (Maton K. , 2009, p. 43), Maton has extended the work of Bernstein and offers an alternative to problematic ‘dichotomous typologies’ by suggesting the reconceptualisation of “knowledge practices in terms of the degree to which meaning relates to its context” (Maton K. , forthcoming, p. 4). *Semantic gravity* is an approach through which the ‘verticality’ of a knowledge structure or practice (whether hierarchical or horizontal) can be defined. Maton has devised a continuum 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 K. , 2009, p. 48). "Cumulative learning depends on weaker semantic gravity and segmented learning is characterised by stronger semantic gravity constraining the transfer of meaning between contexts" (ibid., p. 46). He suggests that "one condition for cumulative knowledge-building and learning may be the capacity to overcome semantic gravity" and that a "wave of strengthening and weakening semantic gravity [is] required for recontextualizing and transferring knowledge across contexts and over time" (ibid., p. 5).

If one were to apply this continuum to 'knowledge practices' over time, the application of knowledge with a hierarchical structure (for example, working on a physics problem) may reveal more frequent moments of abstraction (verticality), or an extended moment of abstraction. On the other hand, as much of the application of knowledge with a horizontal structure in Mechatronics is contextually procedural and requires extended periods of application (for example, the use of software to model a component in CAD/CAM), such a mapping implies fewer 'moments' or shorter periods of potential abstraction, and thus apparently limited 'verticality'. What happens, however, when these knowledge forms are combined in a complex subject such as Design, which captures precisely the intended synthesis of underlying knowledge structures in the emerging region of Mechatronics?

Maton's continuum offers the possibility of analysing the knowledge integration process. By mapping the sequence of the application of hierarchically and horizontally structured knowledge over time, and identifying the different forms of knowledge, a 'semantic wave' may emerge which may shed light on the underlying epistemology and the form of conceptuality evident in student practice in this complex region. It is hoped that such an analysis will provide empirical evidence to support decisions as to both the question of appropriate curriculum design as well as qualification route for the current Mechatronics programme.

Chapter 4. Research Methodology

4.1 Introduction to the methodological approach

Brown and Dowling (in Usher, 1996) describe three moves constituting the ‘research mode of interrogation’: specialise, localise, and generalise. Having established in Chapters 2 and 3 the “theoretical specificity of the research problem” (ibid., p. 147) as being the implications of dichotomous knowledge structures underpinning multidisciplinary engineering practice, “the second move makes explicit the local findings [...] in the context of the particular empirical setting” (ibid.). Chapter 4 both introduces a methodological framework through which to make the findings explicit and establishes the nature of the local empirical setting.

Usher argues that a failure to examine the epistemological and ontological assumptions underlying different research traditions leads to “research normally being understood as a ‘technology’” as opposed to a fundamentally “social practice” (1996, p. 9). Research in the natural sciences “aims for generalisations [...] because they enable predictions to be made” (ibid., p. 10). This is typical of the positivist/empiricist epistemology underpinning ‘scientific’ research. He states that Kuhn, however, “presents science as a socio-historical practice carried out in research communities” (ibid., p. 15) shaped by a particular ‘paradigm’. Having established in the preceding chapters the complexity of the emerging region of Mechatronics, it should come as no surprise that there is no observable ‘paradigm’ and no readily defined community. Such a paradigm would serve to establish a common reference framework “determining important problems [...], defining acceptable theories [...], methods and techniques to solve defined problems” (Usher, 1996, p. 15). This definition speaks to this research at two levels. Firstly, there is no common reference framework as the region crosses disciplinary/regional/knowledge boundaries. This implies fewer defined methods and techniques to solve multidisciplinary problems, and challenges the generic exit level outcomes (lifted from established regions) which determine, for example, that a ‘technician’ be able to solve ‘well-defined’ problems. Secondly, however, as a researcher straddling two fields, namely, sociology of education and engineering, the former with apparent access to a greater range of paradigmatic stances, and the latter (in this specific research context) observably leaning towards technical-instrumentalism, the greatest challenge has been to determine a suitable methodological paradigm for this study. If “knowledge claims [...] are relative to paradigms” (Usher, 1996, p. 16), and I wish to both examine those ‘claims’ as evident in student praxis in an engineering-specific practical context, as well as make ‘claims’ about my observations in a sociologically theoretical context, then I need to be forgiven for adopting not only methodological pluralism as an approach, but also paradigmatic multiplicity. My five-year exposure to the emerging region in its particular institutional context has had a profound impact on this research process, one which will become evident as I attempt to operationalise “the movement between the theoretical and empirical contexts of the research” (Brown & Dowling, 1998, p. 141). In order to do so, however, I need to first elaborate on the context.

4.2 Research context

4.2.1 Facts about the research site

The five-year old Mechatronics Program is offered at a University of Technology (UoT). The Faculty of Engineering is characterised by a strong technical instrumentalist thrust, where “the curriculum imperative is not educational in the traditional sense, but supportive of [...] the needs of the economy” (Moore & Young, 2001, p. 447). This is evident in processes such as ECSA qualification accreditation, regular quality audits, and close relations with industry by way of both Advisory Bodies to inform curriculum decisions, as well as the provision of opportunities for the required Workplace Learning component of the National Diplomas. The Mechatronics Program, being the smallest independent and resource-intensive programme, has an average intake of 35 students per semester, and the entire programme is characterised by a more flexible spatial/temporal approach with a strong peer-mentorship ethic. All students in the first two years have one ‘subject’ per day with built-in self/group study time in a dedicated, equipped laboratory. The programme is entirely electronic and web-based, and students have their own laptops.

The programme consists of two semesterised academic years followed by a year of Work-Integrated-Learning (WIL). The first half of this third year occurs on campus, and is intended to prepare students for their final semester of Workplace Learning (WPL) in industry. Being a relatively new programme, change is ongoing and students are quite used to research practices that enable these changes. One such change, implemented in June 2010, has been the conscious effort to ensure that students are equipped to cope in the third year by way of screening. Progress is monitored throughout the fourth semester and no student may enter the third year without having passed all previous subjects. What this means, however, is that any third-year student as of 2011 is more likely to be successful in fulfilling the requirements of the WIL period. However, this success also manifests as a range of capabilities.

The focus of this research project is the 2011 first semester cohort of the final year. During the WIL semester, students work in a simulated professional environment, resembling an automated, high-tech factory. They are entirely responsible for their week, expected to work from 8.30am to 4.30pm, completing numerous automation tasks in pairs (which involves teaching themselves new 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 only ‘formal’ collective class they have is Engineering Professional Studies (EPS), which I facilitate, and the focus of which is their personal development, the finding of a Workplace Learning (WPL) opportunity for the final semester, and preparation for the professional environment. Lecturer involvement during this semester is merely facilitative. The rationale behind this pedagogic approach is preparation for the realities of independent learning and application of knowledge in industry.

4.2.2 Case study selection

Cognisant of the limitations of a minor dissertation, I have adopted what could be seen as a predominantly single case study approach which “aim[s] to provide an in-depth description” using “semi-structured interviewing” modes as well as “documentary sources and other existing data” (Mouton, 2001, p. 149). However, there are elements of participatory action research (PAR) in my “explicit commitment to the empowerment of participants” (ibid., p. 151) not only through their experience of this research process, but through the research findings facilitating an improved curriculum for future participants on the programme. I have identified one specific project group of five members who fulfil the following criteria: a range of academic ability (as ascertained via academic records), socio-culturally representative of our student base, and who display evidence of differential problem-solving ability.

4.2.3 Researcher position

My role as lecturer, as well as Cooperative Education Coordinator (which entails preparing students for and mentoring them through the WPL period) places me in the unique position of having access to multiple stakeholders who determine what shapes the curriculum. This means that I not only have access to resources which have affected my choice of methods, but also access to the students themselves that lies outside the traditional lecturer-student relationship. My additional responsibilities as Teaching & Learning as well as Curriculum Officer have meant the development of a proactive researcher identity at the site. In practice, this means students are used to contributing to research projects. All twenty students of the cohort in question volunteered to be part of this research, although five were subsequently selected to form a single case study.

There are two validity implications of my role as described. First of all, the critical/emancipatory approach underlying my teaching methodology (which these students encountered in their first year) means that I may have created “social behaviour in others that would not have occurred ordinarily” (Miles & Huberman, 1994, p. 265). This would be true of the reflective practice thrust which underpins the EPS subject I facilitate for these students. Secondly, I have indeed “become part of the local landscape [...which] increases the danger of bias” (ibid.). My various responsibilities mean I have invested a great deal of time and effort in improving this programme. However, the very problem with researching knowledge in this field is that those who have been concerned with knowledge in the past decades are sociologists and not engineers. I believe that ‘knowledge’ research in this region, which has implications for curriculum and qualification decisions, needs to be undertaken by someone close enough to and yet on the outside of the engineering field. I believe my involvement with the curriculum, student practice and industry has sufficiently enabled a broad understanding of the region to make an informed contribution.

4.3 An ‘interactive model of design’ approach

Maxwell and Loomis describe their ‘interactive model of design’ as being “consistent with the conception of design employed in architecture, engineering, art...” (2003, p. 245). The design of a mechatronic system, for example, lies not only in the individual components, but in the connections between these. For each additional variable, the permutations increase exponentially. These connections entail choices and decisions, as the logic of the design is not necessarily dictated by the laws of nature or science, but more often than not by the exigencies of economics, policy, context or feasibility. The primary *question* in mechatronic design (the ‘problem statement’) is always: What must this design do? This is inextricably linked to *purpose*. Why must it do this? The *methods* employed (selection and sequencing of components/ technologies) are framed by *theoretical/conceptual* understanding of what is technologically possible or available within the context. The ultimate success of the design is always measured against *criteria* such as safety, efficiency and cost-effectiveness. The design process is by no means linear, rather a dynamic flow between the macro objective and micro possibilities.

Maxwell and Loomis describe these five core aspects in terms of research design (2003). They highlight the underlying complexity when one is cognisant of the influence exerted by each aspect on the design as a whole. What began as an initial *question* about differential performance in multidisciplinary engineering has come to be framed as one of the impact of ‘different’ underlying knowledge structures. These questions automatically imply both a quantitative element, in that differences are ‘measured’ in some form or another, and a qualitative element to describe the nature and significance of the difference. The wish to illustrate these differences in this context affected my choice of *methods*. I have chosen graphic tools of analysis typical of the sciences, which essentially reduce the data to visual statements apparently positivist in nature, as the conversion of data to graph entails assigning numeric values. However, in order to both assign such values as well as extrapolate meaning (qualitative), I have employed instruments, based on a specific *conceptual framework*, which indicate my interpretation of the data as based on empirical observation in the field and analyses of texts. My choice of *methods* is already an indication of two paradigmatic stances: positivist and interpretivist. The broad *purpose* of the research, however, speaks to my fundamentally critical/emancipatory orientation in the desire to ensure the best possible programme for all Mechatronic students. The serendipitous initiation of the HEQF recurriculation process helped crystallise an immediate purpose: the research is designed to inform the recurriculation process. The research must thus be *instrumental* in facilitating the design of an appropriate curriculum and qualification level. This is yet further evidence of paradigmatic multiplicity. However, “the possible legitimate ways of putting together these components are multiple rather than singular and, to a substantial extent, need to be discovered empirically rather than logically deduced” (Maxwell & Loomis, 2003, p. 251). It is precisely the empirical setting and context that led to the methodological choices and approach.

The measure of any design, be it engineering or research, ultimately lies in its fulfilment of the purpose and its adherence to established criteria. In engineering, the key criteria are: safety, efficiency and cost-effectiveness. These are comparable to key research *validity* issues. 'Safety' can be seen as the adherence to ethical guidelines which "foster the principles of fairness, transparency and reasonableness" and "the obligation not to harm anyone and to help others further their important and legitimate interests" (UCT, 2010). This research is presented in accordance with these values. In the interest of transparency, the intended research was formally tabled during the EPS meeting with the relevant students on 24 February 2011[13]. All students indicated their willingness to participate in writing and were guaranteed the "right to remain anonymous" which entailed the "removal of identifiers" (Mouton, 2001, p. 244).

A good research design, "one in which the components are compatible and work effectively together, [which] promotes efficient and successful functioning" (Maxwell & Loomis, 2003, p. 245) is based on the available resources, "the researcher's abilities and preferences in methods, [... and] the environment within which the research and its design exist" (ibid., p. 247). This research is being conducted in a supportive milieu that extends beyond the programme itself. In our institutional need to recurriculate qualifications from an informed perspective, the findings of this research may be of significance to this process. This being a small scale study, though, the findings will make no claim to 'external generalisability', in other words to "other communities, groups, or institutions" (Maxwell J. , 1992, p. 293). However, it is hoped that the findings will in fact encourage serious examination of the nature of knowledge in the so-called 'information society', particularly since issues of multidisciplinarity have begun to affect many disciplines.

More pertinent validity concerns are those of interpretive and theoretical validity. Despite the use of both quantitative and qualitative techniques through which to view the data from multiple perspectives, it is still required of me to present an account not entirely dependent "on features of the account itself, but [which] in some way relate to those things that the account claims to be about" (Maxwell J. , 1992, p. 283), namely, at an immediate empirical level, the integration of multidisciplinary knowledge in practice and, at a theoretical level, what this reveals about knowledge itself. In the first instance, "accounts of meaning must be based initially on the conceptual framework of the people whose meaning is in question" (ibid., p. 289). The students who are the source of data for this research have provided texts and have been observed in action. Their account of meaning is primarily situated in a practice- and object-orientated environment, and undoubtedly framed by a number of factors that have led to their individual conceptual frameworks. It is for this reason that I have elected to frame their accounts from multiple perspectives: the curriculum they have commonly experienced, their perception of that curriculum, their socio-cultural profile, as well as external evaluations of their practice.

[13] Evidence of this, along with relevant consent forms were submitted with the research proposal.

The second interpretive validity issue concerns *my* account of *their* account. It is here that I have been required to make an interpretive leap. Having approached this research deductively from the conceptual perspective of knowledge structures, I have had access to many examples of not only the theoretical validity, but also the power of a Bernsteinian conceptual framework as applied to the analysis of knowledge and curriculum. However, I am not aware of this theory being extended to analyse micro knowledge integration practices in engineering, which accounts present themselves as predominantly object-based and procedural texts. Where broader practices have been researched, as in Maton (2009) and Carvahlo, Dong, & Maton (2009), the focus has been on underlying social power structures and issues of legitimation based on data arising out of verbal, sociologically-situated texts. Very often in such cases, interpretive approaches based on Critical Discourse Analysis or Systemic Functional Linguistics have been employed[14]. The question of theoretical validity in my research will rest on "the validity of the postulated relationships among the concepts" (Maxwell J. , 1992, p. 291). As I am fundamentally interested in the "potential generative powers" of knowledge as "'real' objective structure[s]" (Luckett, 2011, p. 2), which structures may reveal themselves in practice under certain conditions, I have adopted the critical realist strategy of abduction, "creative reasoning that sets up new relations by locating phenomena in new conceptual frameworks" (ibid., p. 3). This 'framework' draws on the work of Maton and forms the basis of the external language of description (section 4.5).

4.4 Research design and data collection

Working in an engineering HE environment, I have been influenced by the semiotic representations that characterise Mechatronics engineering: schematic diagrams representing macro systems and micro level connections and interrelations of individual components within these systems. My simultaneous academic exposure to Bernsteinian theory meant a recognition of the potential of graphic representations of this theory to speak to an engineering audience. As such, I have elected to use a typical semiotic representation from the region as a metaphor for the actual research design: that of a PLC control system. This 'mode of interrogation' attempts to move "toward a coherent organizing of the research in terms of theoretical specialization and empirical localization" (Brown & Dowling, 1998, p. 143) by locating the theoretical in an object metaphor arising out of the empirical setting. However, the use of such a 'technology' is not intended to reduce the research to positivism, rather as a framework through which to access data describing 'social practice' and which framework is indicative of the researcher being situated in a specific context of social practice (Usher, 1996).

[14] It is important to note that the focus is not the different world views a student brings to bear in attributing meaning, so the tools of analysis are not discourse related. I am fundamentally interested in the epistemological foundations and their potential ordering of the way in which knowledge integration may work. This is not to say that an analysis of student texts in the context of the implications of power relations or legitimation is not worthwhile. Indeed, it is apparent that there is room here for further research.

4.4.1 Research design metaphor

A Programmable Logic Controller (PLC) is a means to connect a dynamic system and control its functioning. It can have hundreds of 'inputs' which are usually sensors and switches indicating the status of all existing components and subsystems (these could be heat, pressure, rates of change, on/off status). The 'outputs', actuators that initiate or terminate processes in the system, are the visible result of an input *being understood* and a process being initiated or monitored by the controller. In order for the PLC to control the system, it needs to *interpret* the input information and *translate* this to be read as an output. This interpretation and translation exercise is what the selected programming language does, the so-called 'embedded system' or 'software'.

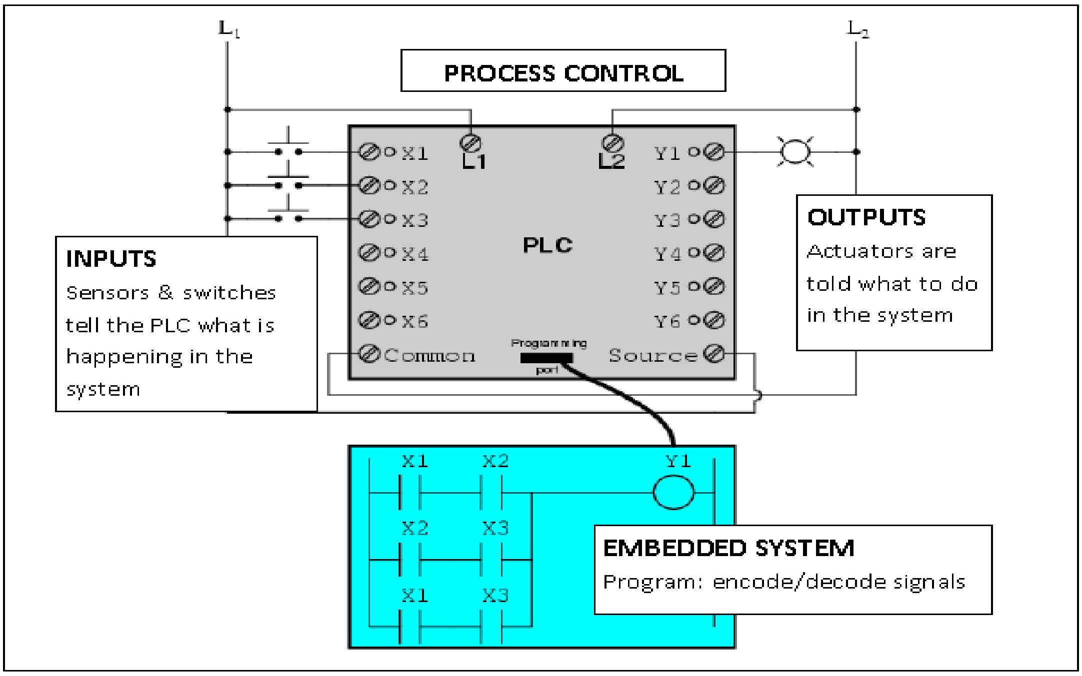

Figure 3 Simple overview of PLC layout (adapted from Wright, 1999)

The metaphor that this system represents operates at two *process* levels in this research (see Figure 4), and each speaks to a different part of the research question:

1. *How do final year engineering diploma students integrate and apply multidisciplinary knowledge?*
2. *What might the process reveal about the nature of the knowledge itself and the enabling conditions for integration?*

4.4.2 Level 1: The student's process

Inputs

The first part of the question concerns the student's process. The PLC metaphor may be employed as follows: the inputs are the knowledge and experience the student brings into the process. The focus of data analysis is the student's *perception* of what counts as knowledge in this context. In preparation for WPL interviews where students are routinely asked to elaborate on their practical and academic knowledge, I asked all twenty students of the cohort in question to see if they could identify what types of knowledge they needed for the various stations, as well as their Design and EPS work (Appendix B1). I selected my case study group on the basis of this exercise as their 'knowledge maps'[15] were indicative of the range of knowledge perception in this particular cohort. I was interested in what students identify as relevant knowledge, to what extent this is framed by 'subject names', and whether or not they could identify the disciplinary roots of 'integrated subjects' (C--). By using an adaptation of Maton's *semantic gravity* continuum (to be detailed in the following section), I was able to determine the extent of the context-dependency of the student's knowledge framework. In order to support this, however, I have also elected to include a profile of each student based on demographic information and academic records.

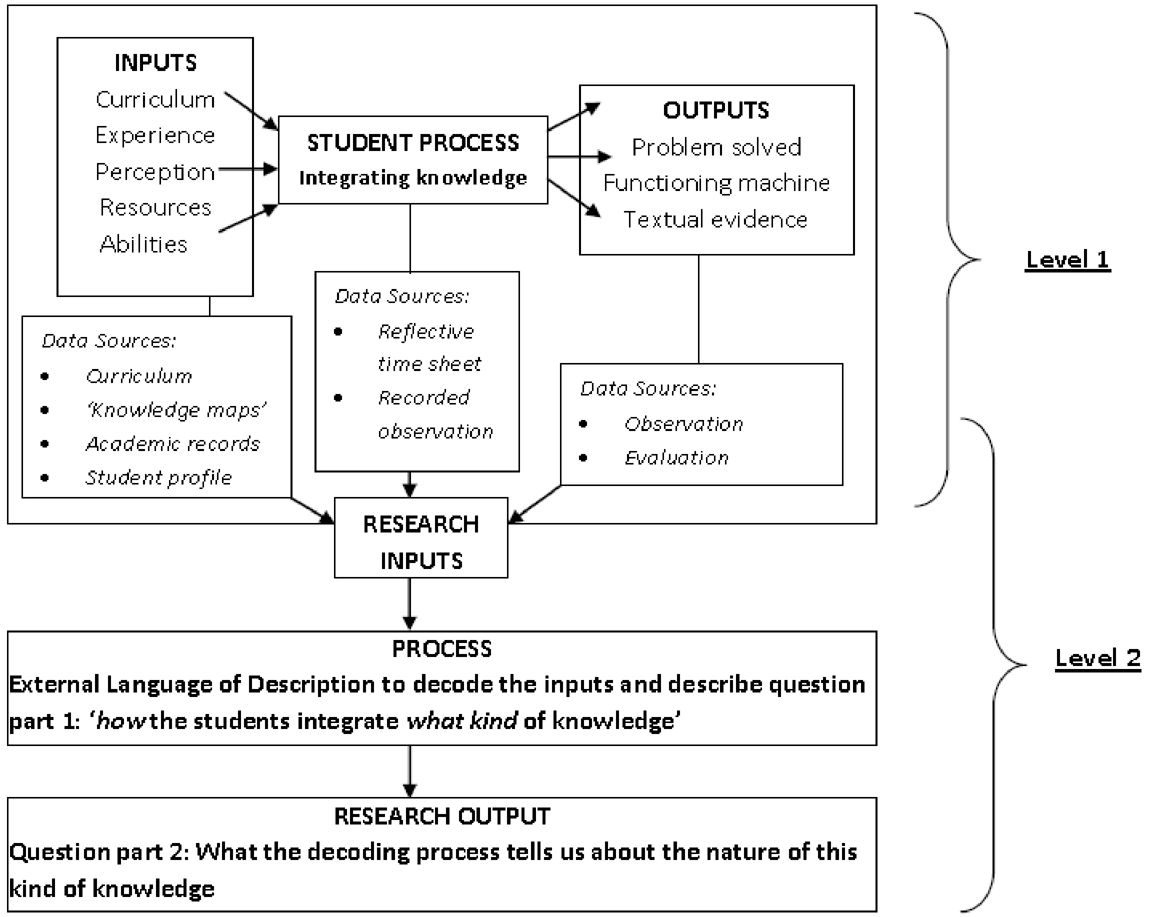

Figure 4 Research design

Process

The second phase of the first level is the actual knowledge integration process. Firstly, I was interested in *how* the individual students talk about knowledge that they have applied in retrospect. There are two sources of data. The first is the compulsory electronic weekly time sheet detailing all activities for every hour of every working day. Having read nine weeks of time sheets, my selection of this particular case study was also supported by their being able to record their actual working

[15] I am aware that Gamble (2010) uses this term, but I am simply referring to their physically 'mapping' and naming types of 'knowledge' on hard copy sheets of paper.

process to varying degrees.[16] I elected to analyse, using the adaptation of Maton's semantic gravity continuum, the time sheet descriptions of one typical week, Week 9, in the student's semester. The purpose is to determine the general range of knowledge drawn upon, the activities regarded as significant, and the degree of verticality evident in the student's reflection on their actual practice.

As one week may not necessarily reflect engagement with knowledge practices that fully encompass 'Mechatronics', the more important perspective to understanding the knowledge integration process entailed short in-situ semi-structured video recordings of the case study group describing problems they were attempting to solve on their Design project. I have selected three short problem-solving recordings on the basis of their collectively being representative of Mechatronics knowledge. A fourth recording is included to support the way in which the fifth group member works with knowledge. The focus is the knowledge on which the students draw to solve these problems, and the degree of context-dependency evident in these processes.

Outputs

The students' inputs and processes lead to an output. In this case, the output is evidence of integrated knowledge. I had initially anticipated being able to use Bernstein's evaluative rules as a theoretical framework through which to address the interpretation of criteria. However, there is little ambiguity here. In practice, all understand that 'integrate knowledge' in this context means the machine/system works and problems were solved in order to accomplish this. I have elected to include the final assessment of semester five student performance which took place on 26 May 2011. This performance is a 'customer presentation' during which the project groups formally present their design projects and are questioned by a panel of invited industry specialists and faculty members. The generic engineering diploma exit level outcomes are used as criteria (Appendix A). The final mark awarded each student is the average, in this case, of six different assessors. It is relatively safe to assume that in this context this assessment would be a fair enough indication of evidence of a level of knowledge integration.

4.4.3 Level 2: The research process

The second level of the research design regards the research process itself. As can be seen from the PLC research design illustration (Figure 4), all the above data (the student's inputs, process, and outputs) represent the research inputs. The student processes the available knowledge (whether curricular or experiential) and produces an output. The student is his/her own 'translation device' (Bernstein B. , 1996, p. 135), which I cannot 'see'. In order for me to be able to produce an output, in other words attempt to interpret the student's process and make claims about the nature of the knowledge evident here, I need a translation device, "whereby one language is transformed into another" (ibid.). This takes the form of the External Language of Description (ELoD). In other

[16]There are students in this cohort who have found the reflective time sheet a difficult task. Much as I would have liked to include such an example, it proved too difficult a research task as the only remaining evidence of potential knowledge integration was the product: the machine, either functioning or not.

words, I need to create my own 'programming language' to encode the research inputs and decode these empirical observations in terms of a particular theoretical interpretation system.

4.5 External Language of Description

In order to identify *types of knowledge* evident in student practice, the *manner* in which this knowledge is applied to achieve integration, and the *degree of context-dependency*, I will be applying the ELoD across three layers of analysis.

Table 2 Layers of analysis

Layer	Focus	Tools	Source
1. Macro	Individual students' Knowledge Profile: *context-dependency*	Bernstein: classification & knowledge structure; Maton: SG (adapted)	Text: Student Knowledge Maps
2. Meso	Individual students' reflective description of practice: *individual semantic wave range*		Text: Student weekly time sheets (Week 9)
3. Micro	Group problem solving moments: *Collective/individual semantic wave range*		Interview: Group

4.5.1 Macro analysis

The participant purpose of the 'knowledge mapping' exercise was to encourage explicit awareness of knowledge and the curriculum. The ELoD devised to interpret these maps evolved after I had assigned the task. It was clear that students had multiple ways of naming 'knowledge', and the categories (Table 3) emerged after reviewing all twenty knowledge maps produced by the cohort of students.

Table 3 Example of knowledge map coding scheme

Student	Knowledge required for Design Project	Knowledge-naming location			Kn. Str	Class.
		Epist.	Curric.	Praxis		
A	• "Flow control; Behaviour of air in pneumatic systems" • "Organisational skills: time management"	√Physics	x	x $\surd P^{e}$	↑ ↔	C^{++} C^{--}
B	• "Fluid mechanics; Applied strength of materials • Computer-Aided-Manufacturing"	x	√ √	x $\surd P^{i}$	↑ ↔	C^{+} C^{-}

I identified instances of knowledge naming as constrained by the 'subject' name (that in the formal curriculum). Secondly, I distinguished between the naming of knowledge as praxis, either as an applied subject (such as Computer Aided Manufacturing, which has no other naming potential) or references to actual practice, such as 'time management'. The third location of knowledge is epistemology, which was indicated when the subject itself was not named, but the underlying concepts were described. In addition to assigning 'locations', I identified the relevant Bernsteinian hierarchical/horizontal knowledge structure, as well as the classification of that knowledge in the existing curriculum.

From the example in Table 3 it can be seen that students identify 'practice' knowledge which needs to be differentiated. I opted to devise a praxis code as follows: $\mathbf{P}^i$ refers to knowledge practice procedures internal to the machine/system of the region itself, in other words, Mechatronics. $\mathbf{P}^e$ refers to practices external to the machine/system, in other words, generic engineering, social or professional practices. I observed during the analysis of the knowledge maps that references to both these types of practice may occur in language that indicates degrees of verticality. In order to reflect this, the ELoD needed to evolve.

4.5.2 Meso and Micro analysis

Table 4 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

In order to differentiate degrees of verticality for the analysis of time sheets (the focus of the meso analysis) and the texts arising out of the interviews (the micro analysis), I turned to Maton's *semantic gravity* continuum (2009). I found I needed to develop a way to interpret the student texts that allowed for predominantly object-orientated, technical procedural descriptions. The aim of using Maton's continuum is to establish whether or not the student demonstrates a *semantic wave* in integrating knowledge. By identifying different statements/knowledge claims over time, and assigning the above categorisations, one can track the movement of meaning-making in relation to the degree of its context-dependency. However, I have already indicated that the students refer to knowledge practices both internal to the machine or system (disciplinary-based Pi) and external (generic, social/professional practices Pe)[17]. Students routinely describe drawing on knowledge from their personal experience outside of the machine/system, for example in their sporting environment, or something they have seen on the Internet. Making an inference about that external knowledge (eg. "the cam shaft of a hunting bow is very efficient) is different from making an inference about the immediate machine/system ("these fluid muscles are not very efficient"). Students also record everyday activities, such as taking breaks or going about personal business, which mark important moments of potential problem-processing. As my intention is precisely to describe *all* the knowledge required to make meaning in this region, I needed to differentiate

[17] My initial thought was that this distinction could be described as the difference between an epistemic relation (ER) to the knowledge or a social relation (SR) to the knower structure (Maton K. , 2009). However, the P^e practices fall into both categories, albeit that the epistemic elements are not 'Mechatronics'. The precise nature of the P^e practices will be discussed in Chapter 6.

between the two broad locations of knowledge, as well as indicate the degree of verticality in each. I have, thus, developed Maton's semantic gravity continuum as follows:

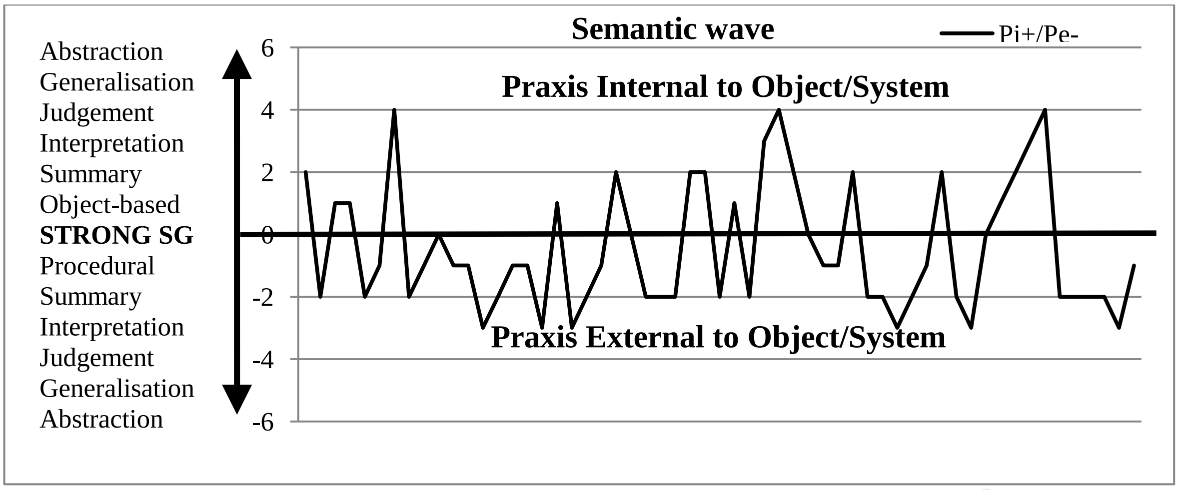

Figure 5 Adaptation of Maton's semantic gravity continuum

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. This graphic is intended as a representation device, and not a traditional graph. I have used the adapted continuum (Table 4) to code the student's knowledge maps, so as to indicate the degree of verticality evident in how they perceive what counts as knowledge. I then apply the graphic Pi/Pe representation (Figure 5) to code the Week 9 time sheets of each student in this case study to determine the range and nature of knowledge drawn on in a typical week[18]. This enables a mapping of the individual student's *semantic wave*. By applying a similar analysis to the four selected problem-solving moments, I hope to establish a collective *semantic wave* which reflects the possible 'conceptuality' of mechatronics knowledge integration in practice.

What I hope to identify through an analysis using the described ELoD is *how* students work with *what kinds* of knowledge in this complex emerging region and whether or not there is evidence of "the ways in which the structuring of knowledge itself works to shape social practices, identity, relation and consciousness" (Maton & Muller, 2006, p. 21)? Do the students recognise and apply rules internal to the logic of the knowledge itself? What is this logic? Is this recognition and application dependent on enabling conditions such as the learning paradigm underpinning the semester? It is my hope that findings will help to inform the recurriculation of the two intended qualifications in which the notions of conceptuality and contextuality need to be made explicit.

[18] In according values between 0 and 2, in both Pi and Pe regions, the literal use of words was used as a coding guideline. This is often, however, problematic. The intention of the semantic wave mapping is primarily to determine degrees of verticality, particularly beyond the 'judgement' range. Furthermore, what might be regarded as mundane activities have been coded as they indicate both the student regarding these as significant as well as potential problem-processing moments.

Chapter 5. Analysing the knowledge practices

5.1 Explicit formal sources of knowledge

Before I begin the analysis, I need to establish the explicit sources of knowledge available to the students during the Work-Integrated Learning (WIL) semester. The following table represents the curriculum as the student has experienced it in the previous two academic years. I have explained the significance of the knowledge structures and classification in detail in chapter four and am merely presenting this as an overview which will inform the students' knowledge-naming processes in their 'maps'.

Table 5 The mechatronics curriculum

SUBJECT TYPES		MATHS	PHYSICS-BASED THEORY		APPLIED PHYSICS/ MATHS	APPLIED TECHNOLOGIES		PROFESSIONAL/APPLIED	
Knowledge Structure		↔	↑		↕↔	↔		↔	
Originating singulars		Mathematics	Physics/ Maths			Geometry/ Logic/ Grammar		ALL	Ethics/ Psychology
Classification		C++	C++	C+	Integrated	C^{-}	C^{--}	C^{--}	Integrated
SEMESTERS	S1	Maths 1	Mechanics		MechT project 1	Programming			Communication Studies
	S2	Maths 2 (MatLab)	Strengths 2	Fluids 2	Elec/ Electronics 1	MechEng Drawing 1 (CAD)			
	S3		Strengths 3A	Fluids3A	Elec/ Electronics 2	MechT Systems 2	CAM		
	S4		Strengths 3B	Fluids 3B	Elec/ Electronics 3	MechT Systems 3		Design	
	S5			Process Control		Networking & Automated manufacturing	Computer Integrated Manufacturing	Design	Engineering Professional Studies
	S6	WORKPLACE LEARNING							

The primary academic text for semester 5 is the subject guide. However, few read it as a verbal overview is given by the Head of Program during the first week, the focus of which are the intended 'outcomes' for the semester:

- Assemble mechanical parts and assemble modules and components to mechatronic systems
- Install electrical modules and components
- Measure and test electrical variables
- Install and test hardware and software components
- Build and test electrical, pneumatic and hydraulic control systems
- Program control systems
- Assemble, dismantle, secure and transport machinery, systems and plant
- Test and set the functions of mechatronic systems
- Commission and operate mechatronic systems
- Hand over mechatronic systems to clients and provide instructions on operation

- Carry out maintenance on mechatronic systems
- Work with English-language technical documents and communicate in English
- Work effectively as an individual and in teams.
- Engage in independent learning, predominantly using ICTs
- Act professionally, ethically, exercise judgment and take responsibility within own limits

All texts related to the accomplishment of the technical outcomes are in the forms of user manuals created by industry, which are either electronically provided or need to be electronically sourced from the Internet. The texts are object/technology specific, and procedural. The following is an example of an exercise in an industry manual provided for the 'robotic arm' station:

Program the following Pick and Place-Application:

- (1) The robot moves with maximum speed relative from the initial position P10 to the relative position. This position is 40mm above P1 in „+"-Z-Direction of the world coordinate system.
- (2) + (3) Starting from the relative position above P1 the robot moves directly to position P1 with 100mm/s. There it picks the red cube after a delay of 0,5s. After another delay time of 0,5s the robot moves to the relative position above P1 directly with 100mm/s.
- (4) The robot moves with a relative movement from the relative position above P1 with 10% of maximum speed to the relative position above P7. This position is 30mm above P7 in „+"-Z-Direction of the world coordinate system.
- (5) + (6) Starting from the relative position above P7 the robot moves directly to position P7 with 10mm/s. There it puts down the

Figure 6 Extract from robotic programming exercise

5.2 Student perception of required knowledge

5.2.1 Case study profiles

The five students who were selected for this study are representative of the broad demographic. (A tabular overview including academic record information and findings can be seen in Appendix B2)

Table 6 Case study profiles

STUDENT	AGE	1ST LANG	MED INSTR	OTHER	SCHOOL	ORIGIN	WORK EXPERIENCE
L	21	Afrikaans	Afri	Eng	State	SA	1-year intern Automotive
M	21	Xhosa	Eng	Zulu	Maths & Science College	SA	Media technician (part-time)
P	26	English	Eng	None	State	Europe	4 years general engineering environment
R	20	German	Ger	Eng/ Afri	Private	Africa	4 years holiday work - maintenance & programming
T	29	Afrikaans	Afri	Eng	State	SA	4 years motor industry

They range in age from 20 to 29, speak a variety of first languages, and have all had some form of work experience, which is fairly common for a large percentage of Mechatronics students. In addition to the above information, I examined their academic records so as to determine differential academic performance in HE. I have differentiated between five types of subject areas, as per my curriculum analysis: the strongly classified horizontally structured subject of *mathematics* (C++ ↔); strongly classified hierarchically structured subjects (*physics*-based C++ ↑); the middle range horizontally structured, integrated subjects that are *'logic'* based, in other words programming, networking and systems (C-); the *applied technologies* subjects; and *professional practice* (Communication Studies & Engineering Professional Studies).

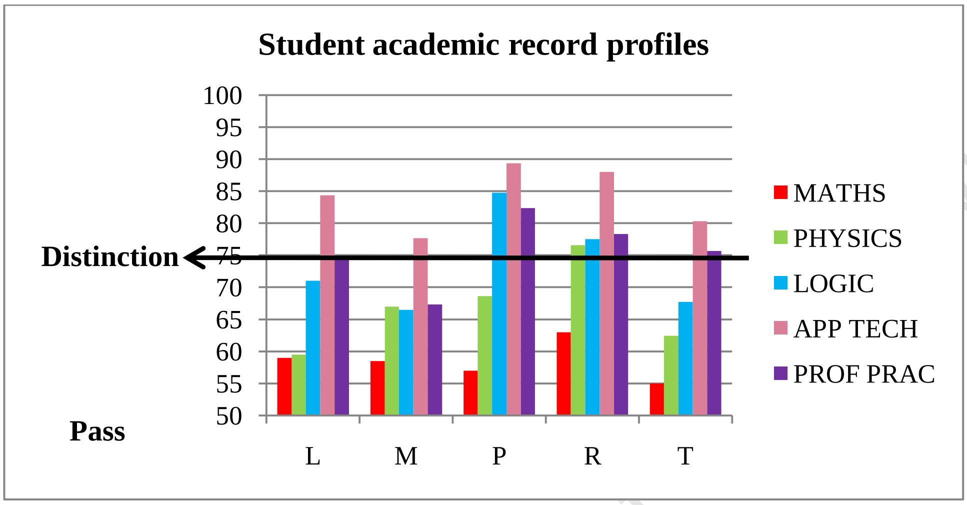

Figure 7 Student academic record profiles

It can be seen from the graph that I have identified the regions in which the students excelled (distinction). What is noticeable is that all of these students fared relatively poorly in mathematics, in comparison to the 'logic' subjects. The fact that these are both recontextualised from horizontal knowledge structures with strong grammars, but that the performance in each case is not comparable will be raised in the discussion. What is also significant is that the closest overall achievement relationship is that between Professional Practice and Logic[19]. Their performance in all the applied technology subjects far exceeds any other. What is also noteworthy is that the only student to fare well in the physics-based subjects is student R, who is also the only student to have achieved a distinction for mathematics in his final year at high school. He is also the only student to have attended a private school.

5.2.2 Knowledge map analysis

The aim of the knowledge map analysis is to establish the parameters within which the general pattern of knowledge integration occurs. Using a technique similar to the differentiation described above, the students' hard copy knowledge maps were colour coded to represent different statements of knowledge, which were categorised according to the above spectrum, but included

[19] This relationship has subsequently been tested in the first semester cohort of 2011. There is a perfect correlation between students failing programming and communication studies.

references to experiential practice-based knowledge internal/external to Mechatronics (Appendix C1). These knowledge statements were coded against the semantic gravity continuum and accorded a value as follows:

Table 7 Knowledge map coding

Semantic Gravity		All Pi disciplinary/ curricular/ experiential	GENERIC practices (Pe)	Coding
Weaker	Abstraction	6	-6	Conceptual descriptions that lie beyond the curriculum
↑	Generalisation	5	-5	Elaborated descriptions / general underlying principles
	Judgement	4	-4	None
	Interpretation	3	-3	Several aspects to one type; interpretive descriptions (eg. "selling yourself" as a Pe knowledge type)
↓	Summarising description	2	-2	Subject field/type: eg. Networking;
Stronger	Reproductive description	1	-1	Subject name: Mechatronic Systems III/ Object specific/general procedural knowledge
	No mention	0	0	

The analysis of the perception of knowledge requirements reveals that only two students, R and T, make any reference to mathematics. Student T (Appendix C6) describes the mathematics required for this semester as "Maths for timing and working out..." whereas student R (Appendix C5) refers to the algebra in relation to process control. These are fundamentally different ways to name this knowledge, as the former is procedural and the latter conceptual. Similarly, Student R describes the logic required as "logical thinking to keep track of program cycle, coordinate systems, and proactive system design". Student T also mentions coordinate systems, but with no further reference to knowledge in this area.

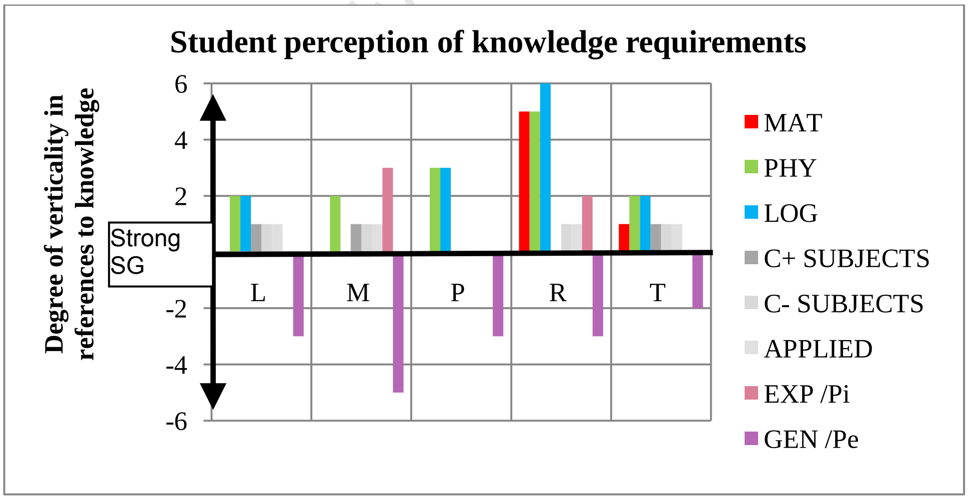

Figure 8 Knowledge map analysis

In cases where the student elaborates and clearly extends the description of required knowledge, I have assigned values in the upper range. It is worth noting that student P (Appendix C4) makes no reference to curricular knowledge in subject terms and does not extend his description of knowledge into the abstract. And yet, he is the highest overall academic achiever of the entire cohort. The fact of maturity (26) and four years' working experience may be significant. However, Student T similarly has four years experience in industry, and is also older.

Student M was the only student to elaborate on internal and external praxis. He writes of learning from peers and academic practicals; he refers to "love for a subject" and "patience" as knowledge requirements, in contrast to student R who speaks of "organisational skills, time management, leadership", the more generic professional practices. Student M's representation of his knowledge map is an object-orientated graphic reproduction of each station, carefully labelled, with dense writing and many full sentences (Appendix C3).[20] This stands in stark contrast to the systematic, verbal and tabular map of student L (Appendix C2). In line with the participatory action research (PAR) ethic, the intention of these maps was to empower the students to become aware of 'knowledge' per se. Students M and L commented on the process in their weekly time sheet. Their comments are presented verbatim:

> *"[I] enjoyed the Knowledge map yet wished I could have done it without being asked to do so before time as learning about all the components was a good thing as it never at any point crossed my mind to ever do that". (Student M)*

Student L's comment was very illuminating as it alerted me to the question of disjuncture between the assumed theoretical foundations and practice. He writes:

> *"Started with my knowledge map. Thaught it was stupid at first but the more I looked into it and wrote down what I did, the easier I found it to name all the relevant parts. I also found that a lot of our learning has only started when we started with our P1 this semester. Also realised that I knew much more than what I thaught. Thinks that this will help me with the other stations that we will be working on. Feels like the previous t[w]o years of studying is a waste compared to all the things I have learnt in the past 7 weeks." (Student L)*

What can be deduced from the above analysis are the very different perceptions of what counts as knowledge and the very different ways of naming that knowledge. Figure 8 helps to establish a potential range of conceptuality that the students take with them into the knowledge integration process. What we might anticipate is the likelihood of high levels of verticality in the case of student R for example, and the possibility of a more social orientation in the case of student M.

5.3 Knowledge integration patterns

Each of the five students' week 9 time sheets have been analysed according to the ELoD. Statements have been dissected into identifiable moments indicating either a different form of knowledge that is being referred to or a shift in the way the knowledge is described. These

[20] This is in fact precisely what my instruction suggested: "sketch out the station areas" (Appendix B), but Student M's was the most literal interpretation.

statements originate from an MS Excel template which divides the week into five days, and each day into hourly blocks, starting from 8.30. Student descriptions in these blocks vary considerably. They can contain dense text describing what may have taken 10 minutes. Alternatively they may simply state a phrase which ‘summarises’ what they did for a number of hours. I have used their end of week reflections to inform coding decisions in certain cases. Where the knowledge refers to a Mechatronics related task/process, the semantic gravity values are in the positive range (1 to 6); where the knowledge refers to generic engineering or social/professional practices, the semantic gravity values are in the negative range (-1 to -6). All knowledge types have been colour-coded as follows:

Table 8 Knowledge colour coding

MEC	Mechanical
ELE	Electrical
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

These data were analysed using the MS Excel 2007 spreadsheet functions. Once values had been accorded according to the Pi/Pe scale and knowledge types named, line graphs were generated. I will present an extract of the coding spreadsheet for each of the five students so as to establish the validity of my interpretation of their statements according to the ELoD. However, my analysis will focus predominantly on the line graphs that have been generated. The full coding spreadsheet per student can be found in the Appendices (D) and will be indicated in each of the following sub-sections. I have elected to present the analysis of the five students’ weekly knowledge integration process following their partnership grouping: Student M (whose partner is not part of this study); Students L & T; Students P & R. The reason for this grouping is that the pairs would be working on similar weekly stations/problems (mainly Monday to Wednesday). The two sets of pairs, furthermore, are working on the same aspect of the group design project (mainly Friday). Student M’s contribution to the group design project is by way of logistical support, but this is not indicated during week 9. Grouping the students in this way enables a comparison of how they refer to similar experiences during the week, and it will be seen that the partnerships are not coincidental. All timesheet quotations are presented verbatim.

5.3.1 Student M: time sheet analysis

On Thursday mornings all semester five students have Engineering Professional Studies, which I facilitate. I have chosen to include the Thursday sample of Student M’s time sheet coding (full week analysis in Appendix D1), as it provides a good indication of the range of knowledge outside Mechatronics with which these students engage. (All the seminars indicated are student led.) It also provides a good indication of the way Student M describes his day. The pattern is relatively consistent, predominantly either technical or practical summaries (2/-2). There are, however, many 'reproductive' moments (1/-1), such as exact time at which something began, or the very first entry 'got my laptop ready'.

Table 9 Student M sample time sheet coding

Thursday	TIME	KNO	Pi/ Pe	Pi Coding	Pe Coding
got my lap top ready and checed my mail.meeting started by S---	8	GEN	-1		Reproductive: practical process
Meeting ended and lunch for 15min ??		GEN	-1		Reproductive: practical process
downloded cnc program	9	LOG	2	Summary: technical process	
Safety seminar began and video began to make use aw[ar]e	10	GEN	-2		Summary: practical process (GENeric)
Safety awareness campiness continued with the class interaction at 12:15 Safety seminar ended	11	GEN	-2		Summary: practical process (GENeric)
Manufacturing seminar began as they looked as a companies that we would go into as this is a big and broad concept Seminar ended at 1:07	12	GEN	-3		Interpretation: Personal significance
10mints lunch and At 1:55 we started with Ms W giving an update on the job application process	13	GEN	-2		Summary: practical process (GENeric)
Arranged and asked Ms W permeation to call R... at [Company]	14	GEN	-1		Reproductive: practical process
Downloaded the Mach 3 software	15	LOG	2	Summary: technical process	
I received a call from a company in Canada regarding CNC control software.		GEN	-2		Summary: practical process (GENeric)
They where very help full and continued to promise to email me more information	16	GEN	-3		Interpretation: Personal significance

Student M's week 9 (Figure 9) is dominated by two areas: the problems with control (logic) on the processing station, and a great deal of generic practice, in this case, including a job interview on Tuesday. He often provides meticulous procedural detail (1/-1) with regard to non-disciplinary knowledge: "Went on the RS components catalogue [electronic] and started looking for a contact we needed for welding robot project .found one at 1:30 on page 237. at 1:40 i then when to make a call to RS components".

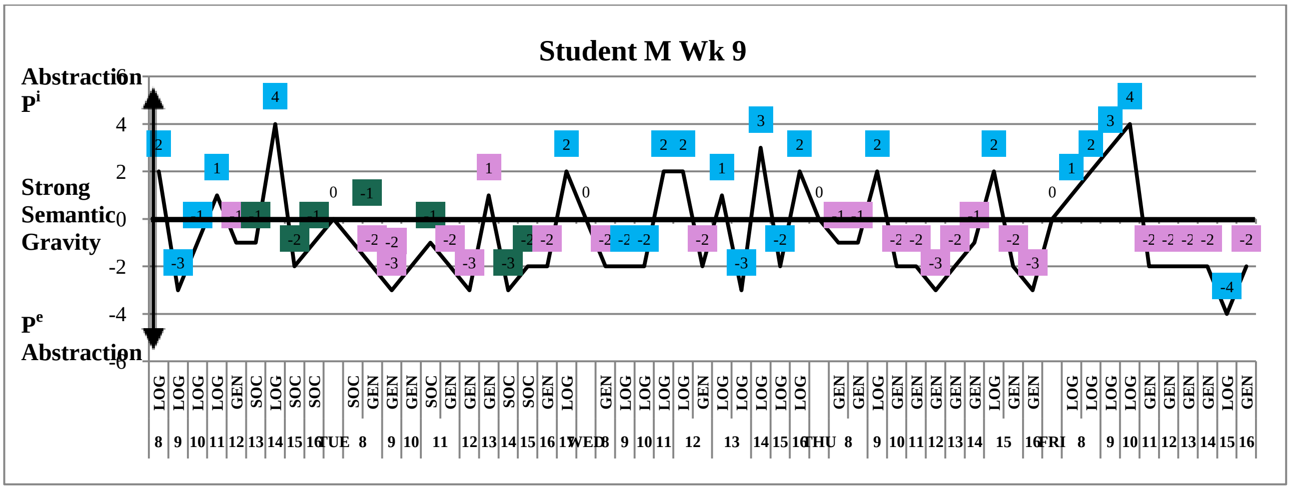

Figure 9 Student M semantic wave week 9

He also describes his feelings about most encounters with other people, such as the job interview: "I enjoyed the interview as both the guys [that] interviewed me and answered every question confidently"; or his discussion with the Program Coordinator: "He expressed this concern about where we going to work asking question on what we like and love to do" and he comments that "I was amassed that he actually cares" (amazed).

The station this student is working on involves process control of liquids. This means the observation, recording and control of flow rate, pressure, temperatures, and volume. This is the station where physics and mathematics would be most evident. However, the student's description is predominantly concerned with procedural completion of workbook exercises in relation to control (logic). There is no indication of the type of knowledge involved. Student M is the lowest overall academic achiever of the group, but achieved a distinction for the applied technologies. His *semantic wave*, ranging from technical to generic decisions (4 to -4), suggests a very procedural approach and a valuing of the social elements. He has the most references to other people, peers, and mentors.

5.3.2 Student L: time sheet analysis

Table 10 Student L sample time sheet coding

Friday	TIME	KNOW	Pi Coding	Pi /Pe	Pe Coding
Timesheet update	8	GEN		-2	Summary: practical process
I started the day by roughly designing and the building a test rig to test wether a rachet tool	9	MEC	Summary: practical process (tech)	2	
would work with the muscles. I struggled to remove the shaft and	10	MEC	Interpretation: technical prob.	3	
went to the Mechanical workshop to get help in removing it.	11	MEC	Judgement: decision to get help	4	
Myself and J also went to Mr. Bearing to see if we could find the correct single way bearings.	12	GEN		-1	Reproductive: practical process
Need to get shaft size and get back to them because it needs to be sent from JHB.	13	MAT		-3	Interpretation: generic technical problem.
Ph. will bring a few from his house. Continued in the rig. As soon	14	MEC		-4	Judgement: implies they decided to ask Ph. for help
as I mounted the rachet I realised that we would have same problem with it that we had with the	15	MEC	Interpretation: technical prob.	3	
bicycle rachet. I told my fellow group members and scrapped the idea. Mr H added that	16	MEC	Judgement: re tech.solution	4	
we should firstly test the crank. I proceded in disasembling the previous rig.	17	MEC	Summary: practical process (tech)	2	
Assembled the crank and all its components, mounted it on a flat piece of wood.		MEC	Summary: practical process (technical)	2	
We can now connect the bycicle gearing and test it.		MEC	Interpretation/ (Judgement?)	3	

Student L was one of the more difficult coding exercises as each statement set (over the week) had multiple references: feelings, opinions, other people, and the knowledge related to the task being described. I have elected to include a coding sample from Friday of his week 9 timesheet (full week analysis in Appendix D2). He uses the first person, full sentences and describes the attempt to solve the motion problem these students are working on for their design project. The overall description is relatively procedural, beginning by establishing what they are testing, where they go and whom they ask for assistance. Technical problems are identified (Pi value 3) and decisions to solve these (Pi value 4) are by way of using existing technical resources (mechanical workshop) or discussion amongst the project group. At 2pm (14 on table 10) they clearly ask a fellow student (Ph) for help, and this has been coded as Pe -4, as the fellow student is not part of their group or project, and represents a turn to the outside world for help. It is this 'outside' help that leads to the solution to the motion problem.

In contrast to the relatively technical focus on Friday, much of the week's activity occurs in the Pe realm, generic professional practices (GEN). These include routine administrative work, such as time sheets, presentation preparation, calls to suppliers, job application procedures, meetings and budgets. Student L regularly interprets these activities as significant, for example, "found the others topics informative and interesting" in reference to their networking related class presentations on Wednesday. References to technical work, however, are limited to mechanical (yellow) and electrical (orange) work.

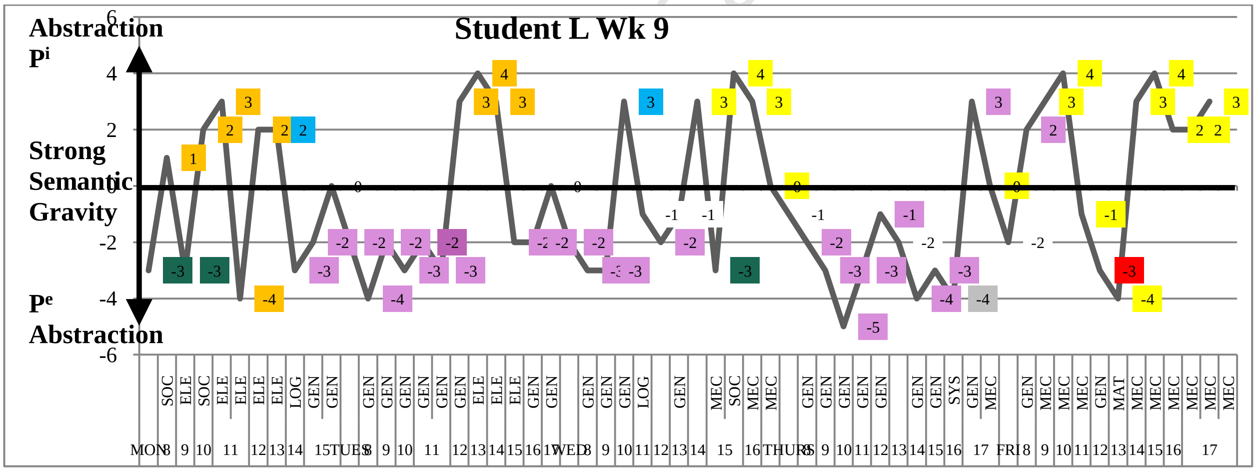

Figure 10 Student L Semantic wave week 9

The flow is relatively consistent: Object-orientated description (Pi 1) "proce[e]ded to do the motor panel, we took off all the wires" followed by a summary of the process (Pi 2), the identification of a problem (Pi 3) and a decision to take some sort of action (Pi 4). There are two potential references to a general technical principle (the last entries on Wednesday and Thursday). These refer to the decision to use a one-way bearing. Instead of distilling the principle, the student's references remain framed by the mechanical structure itself: "because the rached [ratchet] was too rugged. The number of clicks was far too less for our application. Thus using the one way bearings, or even the internals of a rachet tool [would be necessary]". I have accorded these references an 'interpretation' value (3). The only general principle (Pe -5) occurs in a comment on Thursday regarding the importance of safety awareness in the class environment.

There are two references to logic, and these are only to the student's 'wireless' presentation. There are no references to physics, and the single reference to mathematics concerns the need to ascertain shaft sizes for the bearing supplier. Student L's *semantic wave* range lies between technical decisions (4) and a single instance of a generic principle (-5) for week 9. His academic record indicates he is the lowest physics achiever of the group, as well as a low mathematics achiever. The absence of identification of these knowledge types in a routine week during the semester is not necessarily surprising, and echoes his knowledge map. The dominance of the recording of generic practices, as well as frequent opinions regarding these, suggests Student L is conscious not only of their significance, but also their relationship to the solving of problems.

5.3.3 Student T: time sheet analysis

Table 11 Student T sample time sheet coding

Friday	TIME	Pi Coding	KNOW	Pi/e	Pe Coding
Arrived	8		SOC	-1	Reproductive: practical process
Reading the manual of the rv2aj. Thi is to reset the origin postion	9	Interpretation: technical problem	LOG	3	
Ment to bmg to find out about one way bearings.	10		GEN	-2	Summary: practical process -
encounter a problem after reading the manual. Wanted to start up the robot bu encounter error message h0050	11	Interpretation: technical problem	LOG	3	
went onto the internet and look what error h0050 is, and found out its an external em . [Emergency stop]	12		LOG	-4	Judgement: decision
this buggerded me around alott.	13		SOC	-3	Interpretation: personal significance
Went arround to the groups to find out where this external ems is. T told me its on the front pannel			SOC	-4	Judgement: decided to ask peers
after tring and pulling out the wires wand traising wires I because	14	Summary: practical process -	ELE	2	
I wanted to find out if I can bypass this ems I went to the internet again			LOG	-4	Judgement: decision
and found out the external ems is actualy on the box itself. This was just a jumper in ourcase not making contact	15	Interpretation: significance	MEC	3	
insurted it again and volla it work. I can now conform that the bateries needs replaising ...		Judgement: what needs to be done	LOG	4	
now I could start going threw the origin setup set by step	16	Summary: practical process -	LOG	2	
did my first setup broblem. All movements is restricted by 90deg.		Reproductive: object-orientated practical	LOG	1	
I redid all the steps and again it cange and I could not get full rotation.		Interpretation: significance	LOG	3	
deasemble and tack out the bataries again to reset everything		Reproductive: object-orientated practical	MEC	1	
started from start.		Reproductive: object-orientated practical	LOG	1	
Sucsess got home posision setup correctly		Interpretation: significance	LOG	3	

Student T (Appendix D3) was the previous student's partner (L) for the semester. He similarly uses full sentences, first person, and presents frequent opinions or feelings about his work. The pattern for the week is fairly similar, with summary (-2) descriptions of generic practices (Wednesday and Thursday), but procedural stages in technical descriptions beginning with a summary of the process (Pi 2), followed by the identification of a problem (Pi 3) and a decision to take some sort of action (Pi 4) . Student T, however, is mainly working on a problem on the robotic arm on Friday, as opposed to the design project focus for student L. What is interesting is that each problem identified on the robotic arm is solved by accessing information on the Internet. As this is situated 'outside' the knowledge the student brings, as with that provided by peers, I have accorded a value of -4, in other words, a decision (judgement) to take action based on knowledge accessed in a broader community of practice. I will detail this aspect in the discussion.

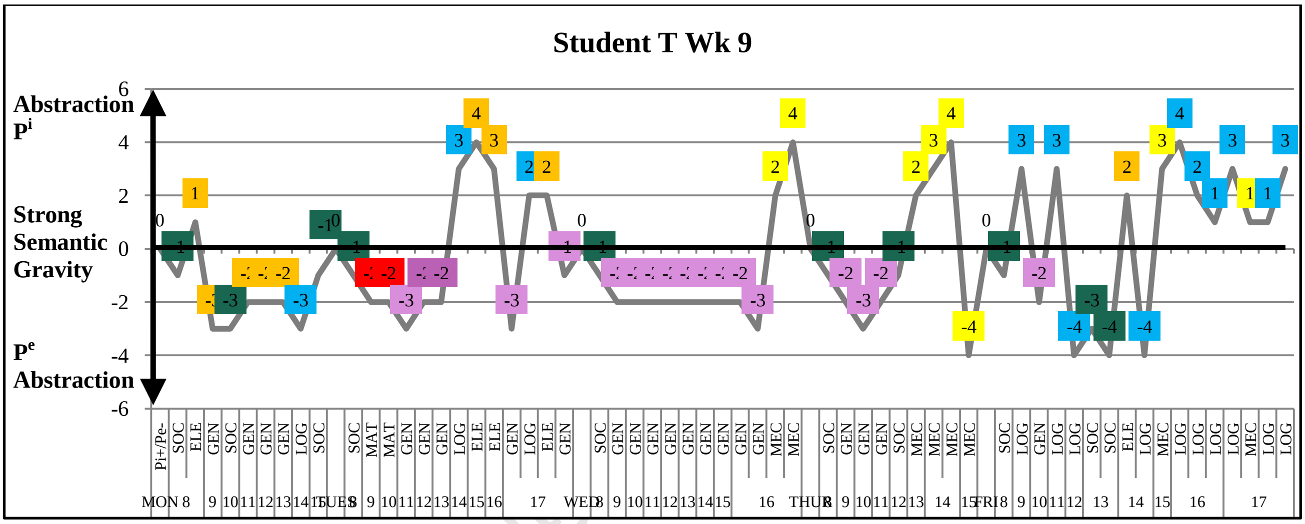

Figure 11 Student T semantic wave week 9

As with student L, most technical references are mechanical and electrical (as they are working on the same station). There are two mathematical references, but both regarding 'calculations of cost', which are essentially generic engineering/professional practices. There are no references to physics, although the motor panel station is predominantly concerned with the control of an electrical system. Student T's academic record indicates he is the second lowest achiever of this group, with the lowest mathematics marks, and second lowest in physics. Although student T is not a native-English speaker, he achieved a distinction in the professional practice subjects, which suggests a grasp of required generic practices. This may be as a result of four years' practical experience in industry prior to and during his studies. Student T's semantic wave range lies between technical and generic decisions (4 to -4).

5.3.4 Student P: time sheet analysis

In strong contrast to the previous three students, student P (Appendix D4) uses no full sentences, no first person, but predominantly noun phrases. Each reference on Tuesday (Table 12), barring one, is a summary (2/-2) of either a mechanical, logic, or generic process. However, at 11 he writes “Started to program steering algorythm [sic] using analog positioning with variable flow valve”.

Table 12 Student P sample time sheet coding

Tuesday	TIME	KNOW	Pi coding	Pi/Pe	Pe coding
Setup of steering test rig	8	MEC	Summary: technical process	2	
Setup of steering test rig	9	MEC	Summary: technical process	2	
Connected up Pneumatic connections of steering rig	10	MEC	Summary: technical process	2	
Started to program steering algorythm using analog positioning with variable flow valve	11	LOG	General: statement about broad system approach; my problem here = this is high end abstract know but recorded procedurally	5	
Programming steering algorythm	12	LOG	All programming could be '4' re judgements constantly made; but recorded as Summary	2	
Programming steering algorythm	13	LOG	Summary: technical process	2	
Programming steering algorythm	14	LOG	Summary: technical process	2	
Worked on HSPA presentation, collating slides and revising information	15 - 17	GEN		-2	Summary: practical process (Generic)

Now, this is an extremely dense amount of epistemological information caught in one statement, as it involves programming (logic), algorithms (mathematics), and variable flow (physics). It will become evident in the micro analysis on problem solving that this student is capable of identifying each of these and explaining the significance at a highly abstract level. I have accorded the value here as a ‘5’ as it indicates the general underlying principle of the steering control required for this project. Student P’s time sheets are all relatively summary-orientated, in fact, precisely what such a time sheet is intended for. He differentiates quite clearly between the depersonalised record of work and the personal reflection at the end of the working week. He notes rather cynically for week 9 that “I spent a significant amount of time assisting in the "this will only take 5 minutes" problems”, an indication that he is clearly relied on by others. What is also clearly evident is the grasp of English language conventions of a native speaker.

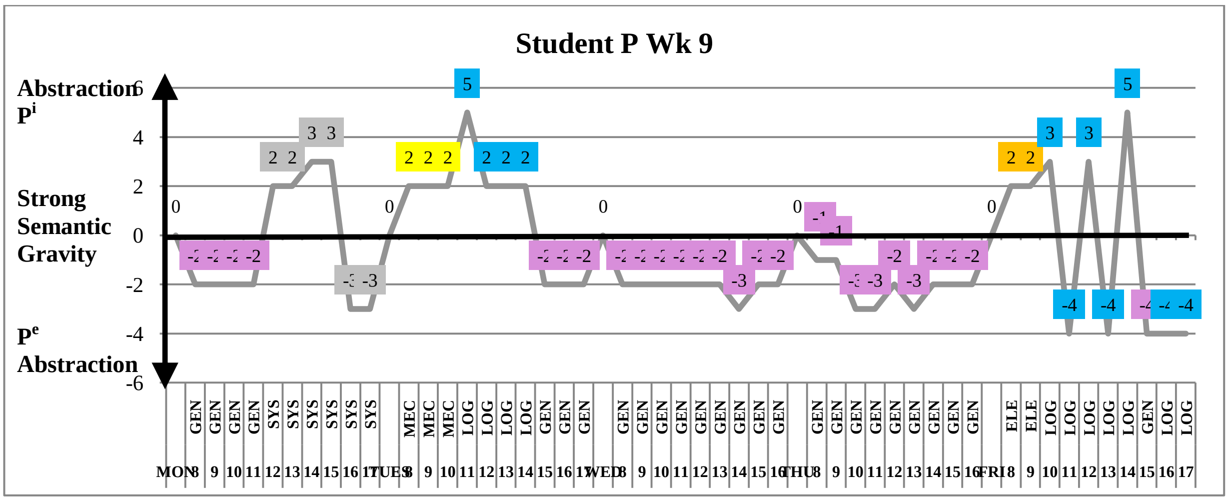

Figure 12 Student P sematic wave week 9

The *semantic wave* evident in the overview of the week suggests a very procedural approach with regard to generic practices particularly. Where there are technical problems (Tuesday and Friday), the wave climbs to 'general underlying principles' and technical decisions. It is evident from the graph (Figure 12) that Friday involved more disciplinary-related work. The problem as recorded on the time sheet had to do with PID control, which involves differential calculus. The student writes that he "researched PID control using s7-1200 on internet [...and then] tried alternative method using range and increasing dead zones and hysteresis[21]". As with the previous example, this extract is dense in its epistemological implications, including mathematics, physics and control logic. Student M, previously, was also working on equipment that involved PID control, but there was no reference to any disciplinary knowledge. Student P refers to the solving of these PID related problems as based on his internet research, and as with student T, I have indicated these steps as (-4): decisions to take action based on findings in a community of practice outside this space. Student P's *semantic wave* for week 9 ranges from technical principles (5) to logic-orientated decisions (-4).

Student P, as previously mentioned, is the highest academic achiever of this cohort, and yet has the second lowest mathematics score (57%) of this group, as well as a 69% average for the physics-based subjects. He makes no reference to mathematics as a knowledge requirement on his 'knowledge map', and yet is quite clearly engaged in mathematical work on the PID problem, which he solves through hours of internet research. This is highly significant and will be raised in the discussion.

5.3.5 Student R: time sheet analysis

Table 13 Student R sample time sheet coding

Wednesday	TIME	KNOW	Pi coding	Pi/e	Pe coding
delivery of festo components	8	GEN		-2	Summary: practical process (Generic)
taking inventory of delivered goods	9	GEN		-1	Reproductive: practical process
helping L with edgecam & starting to write down dimensions of required framework	10	MAT	Interpretation: identifying significance	3	
measuring alu profile and cutting into pieces	11	MAT	Reproductive: object-orientated practical	1	
assembling alu profiles to meet the constrains from the prototype design	12	MEC	Summary: technical process	2	
LUNCHBREAK	13	SOC		-1	Reproductive: practical process
wheel research [internet], i.e. alternative lighter, less rolling resistance	14	PHY		-4	Judgement: making a decision that affects working process - they 'need' less rolling resistance
helping L to cut aluminium 40mm rod & admin	15	MEC	Reproductive: object-orientated practical process	1	

21 "The lag between making a change, such as increasing or decreasing power, and the response or effect of that change." (2011, The computer language company inc.)

Student R (Appendix D5) was partnered with student P for the duration of the semester, both in their routine laboratory work, as well as being project leaders of the design project. As with student P, R also differentiates the function of the time sheet and the generic or socially related work is recorded procedurally/summatively, mostly using noun phrases. He includes ‘lunch’ and ‘tea’ breaks, unlike student P, and these have been accorded (-1 SOC) values. The technical references are specific, and there are clear indications of the underlying epistemology: ‘dimensions of required framework’ (mathematics), ‘less rolling resistance’ (physics), and on Friday ‘calibrating optical diffusion sensors’ and ‘programming HMI to test analog interface’ (logic).

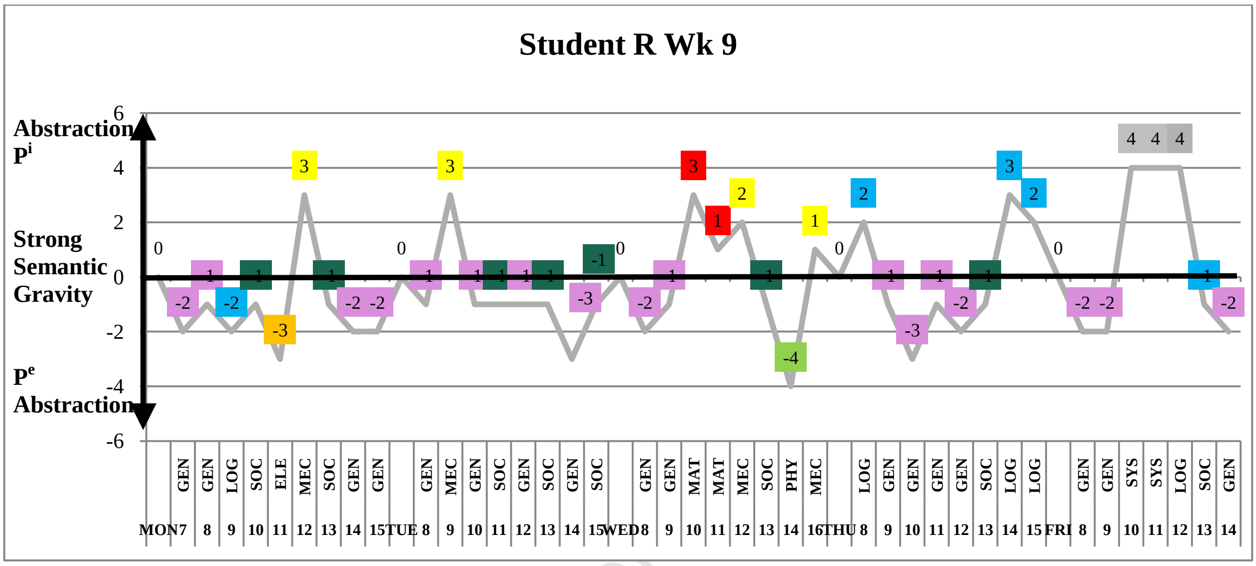

Figure 13 Student R semantic wave week 9

On Tuesday student R had a WPL interview and he records this as ‘technically’ as he does his laboratory work: ‘went home’, ‘got clothes’, ‘checking that all documents are available, rehearsing possible questions’, but there is no indication of a personal opinion in the time sheet itself. In his end of week reflection, however, he describes the experience as positive and speculates on a future in research and development. Student R is the second highest achiever of this cohort after student P, by a margin of 0.2%. He is the only student to achieve an overall distinction in the physics-based subjects, and has the highest overall mathematics mark (albeit a relatively low 63%) of this group. He is also a non-native English speaker, although his use of the language in his time sheets would not indicate this. However, although Student R’s time sheet *semantic wave* range is the same as that of students M and T (range: 4 to -4), he is the only one to reflect all of the knowledge areas I have identified as evident in Mechatronics practice. As with students T and P, there is also a reference to sourcing information from the internet (Wed) which enabled a problem to be solved, in this case one of physics. There is no indication on the time sheet itself as to the general underlying principles (5/-5) or abstraction (6/-6) one may have anticipated based on his academic record and knowledge map.

Collectively the time sheet analysis has enabled a picture of *what practices* the students generally engage in during a typical week, and how they name the relevant knowledge. For the most part there are similarities between the naming or valuing of knowledge on their knowledge maps, and that identified in their time sheets. Clearly, the structure of the week itself, with certain collective periods set aside for what have been broadly termed 'generic' practices interspersed with activities of the students' own control create the impression of an overall semantic wave. However, the evidence of integrating knowledge across such waves is limited by the form (and interpretation of required manner) of retrospective recording of events on the time sheet itself, which is not designed to elicit deeply epistemologically-orientated descriptions of knowledge integration. Secondly, understanding what knowledge is being described is dependent on how explicit that knowledge is to the student himself and the discourse resources to describe this.

5.4 Problem solving practices

In order to move closer to the core disciplinary knowledge and integration patterns, I have elected to focus on one particular complex problem as described in three problem-solving moments in which the students explain (on camera) how they tackled certain challenges. I am fundamentally interested now in moments that demonstrate a grasp of general principles and possible abstraction (in other words values at 5/6 and -5/-6). The key problem on which students L, T, P and R are working is how to achieve efficient motion in an air-powered vehicle they are designing and constructing for an international competition. Once this is achieved the vehicle needs to be programmed to autonomously 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.

5.4.1 Interview 1: motion problem

My 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. However, the movement is restricted to a range of about 10 – 20mm. In order to 'drive' a shaft attached to wheels, students would have to be particularly innovative. The group are experimenting with the notion of using a one-way bearing and gearing system, which are components not supplied by the competition hosts and elements they have not encountered in the curriculum.

I am presenting short extracts from the group interview in relation to 'conceptual' moments (Table 14). The full interview transcription (Appendix E1 – E3) has student L starting off by explaining in object-orientated procedural detail what the muscles are, and where they are physically going to be attached to the structure. Student P takes over and demonstrates precisely how they would work with a one-way bearing, and moves quickly into the underlying physics, describing energy, torque and expansion (turns 7 – 10). My interest in how they had decided to test a one-way bearing leads to student's L and T describing drawing on their experiences in the 'world', that of hunting. Student T explains (turn 15) the principle underlying a hunting bow and draws this into the general principle underlying the system they are attempting to test (turn 17). The solving of this problem involves constantly drawing on their own experiences (hunting 15, cycling 21-26) and references to collectively drawing on each others' knowledge or input.

Table 14 Problem solving interview 1 extract

Question/ summary	Transcription	Turn	Know	Stud	Pi/ Pe	Coding
[L mechanical description of components]	There is actually a spacer that goes on the back and there's a nut that locks into the spacer, so essentially [unscrews nut to maximum] it looks something like that... That'll be a smaller version, it's a lot more exaggerated	7	MEC	P	1	Object demonstration
	So that there is space for this to expand backwards, instead of the muscle contracting...	8	PHY	P	4	Drawing conclusion/ theoretical
	Because of the space, the second it comes past the maximum extension, it's losing energy to the expansion it then has here [points to opposite end]	9	PHY	P	5	General principle
	as well as the fact that at that point you then have minimum torque because of the position of the shaft in relation to the central pivot point,	10	PHY	P	5	General principle
Whose idea was it to use this? [Shaft and bearing]	Mr T's idea. L: Killing people, hunting with a bow, a compound bow.	14	SOC	L	-3	Interpretation/ metaphor
	T: The compound bow uses a cam System for extending the distance of your pull. That works on a variable System for different kinds of poundages(?)	15	SOC	T	-5	General principle - (system metaphor from social/exp world)
	So I was thinking maybe something like that,	16	SOC	T	-4	Judgement; decision to try sth based on experience
	because the distance with the fluid muscle only gives you 2cm, but with a cam system you can increase that and increase the movement.	17	MEC	T	5	General principle
[How they sourced one-way bearings; the bicycle idea]	The problem with that [bicycle system] was the second we built a test rig we realised these muscles don't even contract enough to go one click. We had to find a more accurate system.	23	MEC	P	4	Judgement: decision about action, based on technical req.
[Describe seeing the prototype]	Now their car never reached top speed because basically there wasn't enough torque...	29	PHY	P	4	Judgement
	Because this has quite a high rotation but not enough torque, so you lose a lot of energy because of the way the system works.	30	PHY	P	5	General principle - without torque a car would not reach top speed

I noticed throughout this interview that student R was quiet, as student P tended to dominate. It was clear that the group were used to his leadership, and it was also clear that he had a grasp of the physics fundamentals underling the problems. In contrast to the individual semantic waves based on the written time sheets, the collective semantic wave in this micro analysis is predominantly in the Pi region. What is noteworthy is that two of the moves towards general technical principles (Pi 5) flow from interpretation (-3)/ judgement (-4) in the Pe region. It is also significant that most of the knowledge referred to in the Pe region is contributed by student T, whereas student P manages to sustain a wave in the Pi region.

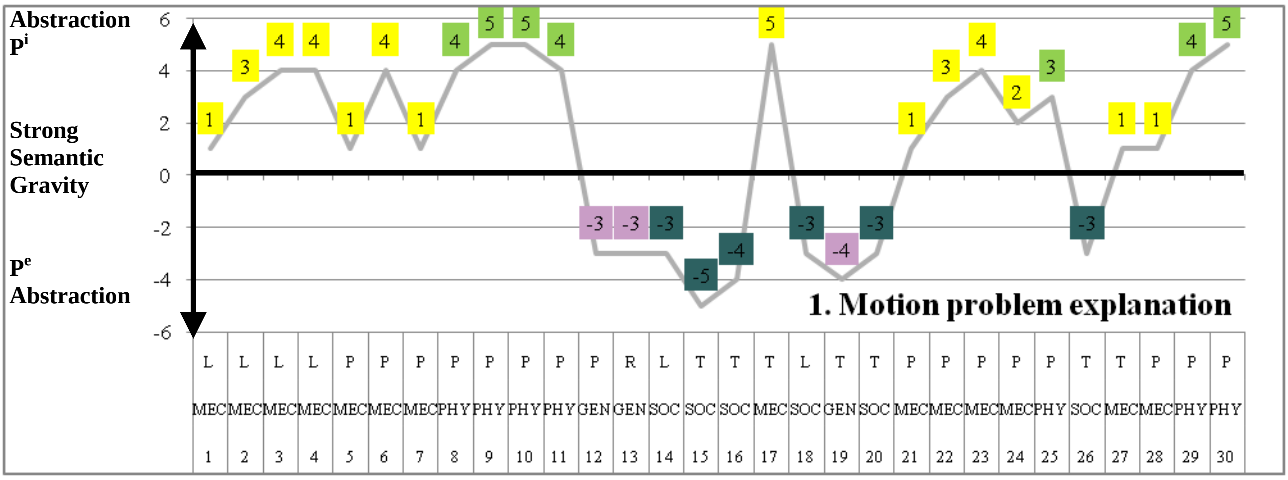

Figure 14 Interview 1 group semantic wave

5.4.2 Interview 2: motion solution

In order to get a better grasp of how they were going to solve the motion problem, I asked students P and R to explain this to me in a second interview (see full transcript in Appendix E2). Student P explains with great technical detail the underlying principles of motion control and steering using a potentiometer, as well as the pulse width modulation technique (PWM) they have employed to program the steering process.

Table 15 Problem solving interview 2 extract

Transcription	Turn	Know	Pi/ Pe	Coding
However, our major breakthrough came when I realised that PLC does PWM...	44	LOG	4	Drawing conclusion/theoretical
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.	45	PHY	5	General technical concept
That's what you can hear with the 'buzzing' - it's actually the solenoids turning on and off very quickly.	46	ELE	3	Interpretation: explanation of significance
A perfect example is the line following. I didn't do any calculations. I thought ok, we need to position the cyclinder, what are our options? I went procedurally through let's try an analogue positioning valve, we tested that and it didn't work.	47	LOG	2	Summary
But from that I realised that the mathematical formulas to get accurate positioning would be such, such and such. [NOTE: student demonstrated calculations/ PWM simulation]	48	MAT	6	Abstraction: (the PWM graphs/calculations)
And then developed very simple principles into quite complicated mathematical algorithms.	49	MAT	4	Judgement/decision
... [How did you know to do that - PWM?] Through a development board called the Arduino, I have used it before.	54	LOG	3	Interpretation based on experiential - own.
They call it analogue out and you just write in a value between 0 and 255,	55	LOG	1	Object' value
but after having googled a large amount on PWM for that I have a much better understanding.	56	SYS	-4	Decision to read up on PWM

This was my first encounter with a form of knowledge difficult to label. 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 mathematically. Furthermore, in a digital control context such as this project, the focus is on programming the system to respond to the 'rules' of logic, which have been mathematically determined, so as to effect physical change. Essentially this use of PWM represents a perfect synthesis of the collective underlying disciplinary foundations of Mechatronics. Their solution was facilitated by hours of internet research (hence the -4 value in turn 56). Unlike the first group interview, there is no reference to people or generic practices. In turns 48-49, student P describes the PWM calculations he had previously demonstrated to me on his computer. I have assigned a value of Pi6 here as the relationship between differential pressure points and movement is captured in the abstract form of PWM graphs and calculations.

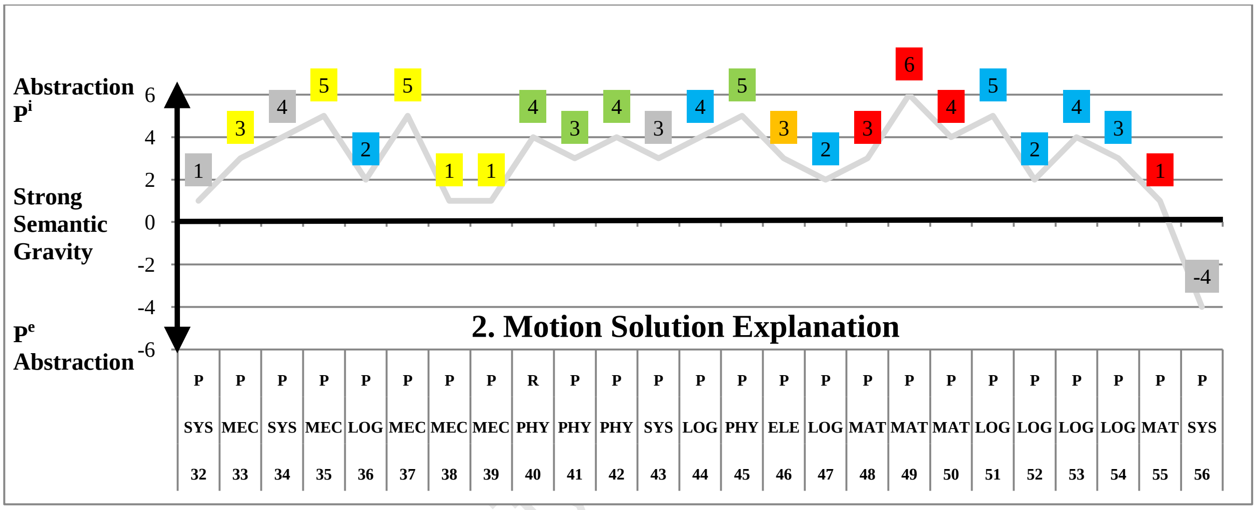

Figure 15 Interview 2 semantic wave

5.4.3 Interview 3: system control solution

As student P was consistently dominant in explaining their problem-solving processes, I wished to ascertain student R's explicit grasp of the fundamental epistemological principles. I managed a third impromptu interview (Table 16) when the group were working on the control 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 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 emphasises the need to concentrate "in order not to lose sight of what has been done and what needs to be done". I have assigned this a value of (Pe -5) as it speaks to an underlying principle of concentration and focus applicable to any complex problem.

Table 16 Problem solving interview 3 extract

Transcription	Turn	Know	Pi/ Pe	Coding
Basically what the problem is is when the car moves in the figure of 8 we need to differentiate between the pitlane, that's crossing the figure 8 and the crossing of the figure itself. So the car needs to decide should it go left or right	66	SYS	3	Interpretation of problem
So what I was thinking for the program was to work out the movement of the car ... [explains logic]	67	LOG	4	Judgement: Decision
[...] we need to change those counts though because we don't know how many lanes/ uhh tracks [means 'laps'] it can go...	70	MAT	4	Judgement: Decision
[...] It is only possible to do it once [enter the pitstop], because as soon as you turn around, you can't enter the pitstop any more because the lane is only on one side	73	MAT	5	General principle (geometric)
The points we get are for speed and distance travelled, so basically we should go round the track as far as possible, because the weighting for distance outweighs speed,	74	SYS	4	Judgement: Decision
so endurance is better ...	75	GEN	5	General principle
The PWM is only for the steering of the wheels...the pneu cyl which steers the wheels is triggered with PWM.	78	SYS	5	General principle
It enables us to proportionally control	79	MAT	4	Judgement
the position of the wheels according to the sensor...	80	PHY	2	Summary
PWM enables us to control it more accurately rather than... fully pressurising the cylinder	81	LOG	5	General principle
The difficulty is ...figuring it out in theory before you go to program it	82	SYS	-5	General principle
when you program it you need to concentrate very well in order not to lose sight of what has been done and what needs to be done.	83	SYS	-5	General principle

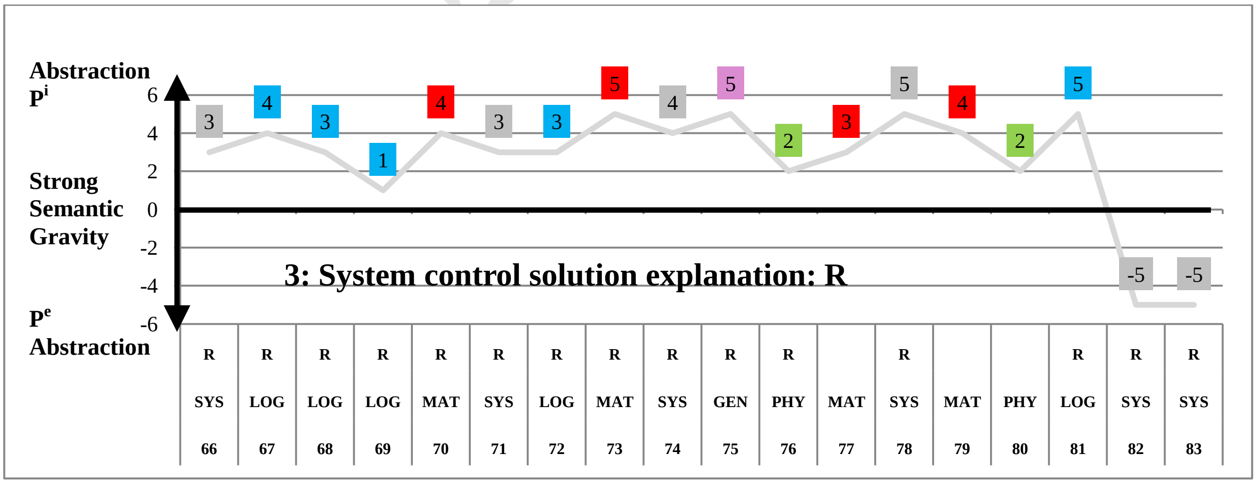

Figure 16 Interview 3 semantic wave

5.4.4 Interview 4: robotic arm problem

Student M's role had always been to provide logistical support, such as marketing and hands-on assistance at the actual competition in Johannesburg, as he was also working on a separate design project. I was, however, interested in how he worked with knowledge, as his contribution to the competition project was vital. A short extract from a longer interview on a problem all students faced on the robotic arm reveals, as with his knowledge map, an object-orientated focus. He describes the entire problem (encountered in week 5) by using his own arm as a metaphor. Although he refers to the general principle of axes reaching their limits, and I have accorded this a value of 5, it is nonetheless an object-orientated description.

Table 17 Problem solving interview 4 extract

What's the problem?	M: let me demonstrate. You have the gripper holding the cylinder in this position, now the robot has to move around and sense the hole.	1	MEC	1	object process
[Demonstrates physically]	Now if you notice my hand holding it in this position.	2	MEC	-1	object process (metaphor)
	Now my hand has different axis. Each axis has diff points [indicates wrist, elbow, shoulder]	3	SYS	-3	Interpretation/ metaphor
	It can't move straight to this side because each axis has reached a limit	4	MEC	5	General principle - the way multiple axes work?
	it has to move here, then undo that limit otherwise it can't move further.	5	MEC	4	Judgement : 'It has to...'

The problem is that the robotic arm is constrained by the space in which it has to operate, and in order to manipulate an item, it would need to execute a series of moves, which essentially could be calculated using principles of geometry relating to arcs. Student M's explanation, however, does not cover this, and the problem is solved through trial and error programming over several days. What is significant is that student M often refers to reaching levels of exhaustion in his time sheet for this particular week and describes how he and his partner agree to sleep on the problems. They always manage to solve the problems the following morning.

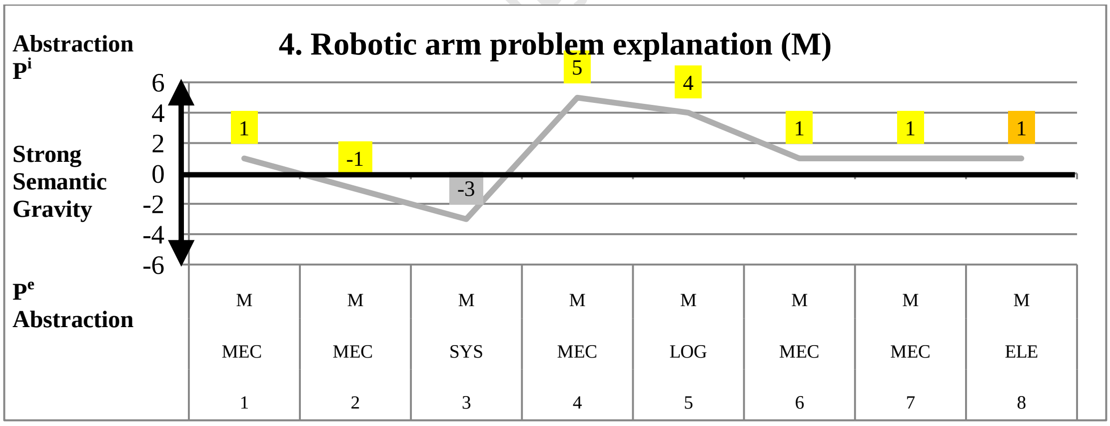

Figure 17 Interview 4 semantic wave

The interviews have provided greater insight into the nature of the epistemic bases of the knowledge on which these five students draw in specific instances, and the degree of context-dependency (verticality) evident in their explanation of solving these problems. The implications of these analyses will be discussed in chapter six.

Chapter 6. Discussion

6.1 Summary of analyses

Three layers of analysis were undertaken in chapter five. The macro analysis attempted to determine a knowledge profile for each of the five members of the case study. This analysis established two poles on a knowledge profile continuum with student R the most capable of recognising the different curricula disciplinary bases, and student M the least, but with greater social awareness. The meso analysis established the range of explicit knowledge drawn on in a typical week, and for the most part matched the macro knowledge profile. Here, the naming of physics-based knowledge for students T and L appears constrained to mechanical and electrical object-based references, while student M focuses on procedural object-based references. Students M, L and T make the most frequent references to social/generic knowledge at different levels of context-dependency, ranging from the procedural (-1) to judgement (-4). In contrast, students P and R tend summarise generic references, and demonstrate greater verticality in the Pi range (disciplinary-based references) between the procedural (1) and general principle (5).

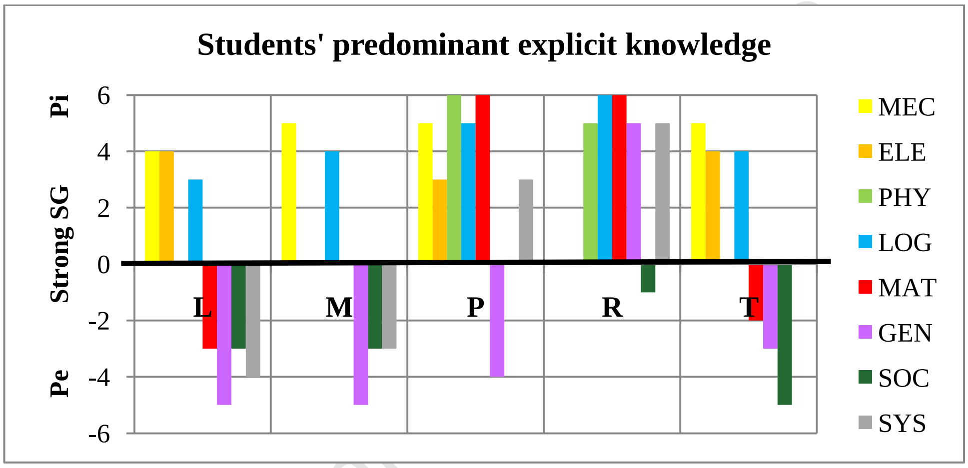

Figure 18 Summary of knowledge references & verticality

Students P and R emerge in the micro analysis as being capable of identifying the fundamental disciplinary principles in the core regions of physics, mathematics and logic. This is not surprising in the light of their overall high academic achievement. However, neither achieved good marks in mathematics (P – 57%, R – 63%), and nor did student P in physics. Furthermore, student P's knowledge perception profile and time sheet gave no indication of the actual degree of conceptual awareness which became evident in the verbal interviews. This may be as a result of being the only native-English speaker, but may also be due to the inherent limitations of both the knowledge map and time sheet data formats. Students T, P and R were the only ones to refer to solving problems (mainly physics and logic) by drawing on knowledge available in the Pe realm on the Internet. However, students T, M and L do not demonstrate the range of verticality in the Pi region that P and R do. Figure 18 represents a summary of the explicit knowledge references as well as degree of verticality for each student following all three levels of analysis.

The most significant finding to emerge from the meso analysis is that there are no references to physics or mathematics (beyond that entailed in dimensioning or costing) by students M, L and T, and that this knowledge is only explicitly acknowledged in the micro analysis by P and R. It is important to remember that the region under discussion is multidisciplinary engineering, and that physics (hierarchically structured) and mathematics (horizontally structured with strong grammar and potential verticality approximating that of a hierarchical structure) appear to be unquestionably regarded as the theoretical knowledge base of all engineering. Furthermore, 50% of the content of the current Mechatronics curriculum is dedicated to physics and mathematics. That there are only a handful of references to physics and mathematics in the over 250 statement sets that have been analysed here is highly significant. However, these references are for the most part references to physics or mathematics *in relation to* the functioning and control of a system using the underlying principles of logic entailed in a particular programming language (horizontally structured knowledge with potentially weakening grammaticality). What is relevant is that only students P and R are able to isolate the underlying core disciplinary aspects at higher levels of abstraction (verticality) whilst engaging predominantly in practices that are essentially shaped by the principles of horizontally structured knowledge: 'serial' in character (Bernstein B. , 2000, p. 162). What the layers of analysis clearly establish is the difference between two sets of students, what they see as relevant knowledge, what they draw on in the knowledge integration process, and how they talk about this knowledge. The question that remains is: what is the difference in 'output'?

6.2 Differential knowledge integration: output

The different ways of working with knowledge manifested in the project process itself. Once the group had moved beyond the electro-mechanical design and construction (of which T and L were very much a part), the project became increasingly complex at a system control level. The core technical group (L, T, P and R) became increasingly dysfunctional at this point, and students P and R took over the project. In my capacity as researcher, in the process of analysing the preceding data, I was aware that the problems the technical group had been facing required the explicit grasp and *synthesis* of higher order concepts (physics, mathematics, and logic) and I suggest that P and R subconsciously felt constrained by the inability of T and L to work at higher levels of abstraction in the Pi region. Student M's role, however, had always been to aid in logistics and marketing (fundamentally social and generic practices in the Pe realm), and he handled this with great success. The reduced team (P, R and M) travelled to Johannesburg with their project and proceeded to take first place the international competition for which their project had been designed, clearly evidence of 'successful' integration of mechatronics knowledge.

Prior to this event, however, the final assessment revealed that all five students of this case study were regarded as successful in demonstrating the integration of mechatronics engineering knowledge through their design and manufacturing of a functioning mechatronic system[22]. Students

[22] Student M's results were based on a different design project, which entailed similar elements but not the same degree of complexity.

M, L and T would be considered high achievers on the Mechatronics diploma programme as it currently stands. However, students P and R would be regarded as working beyond the 'well-defined' problem-solving descriptor that defines a 'technician', particularly in light of the competition judges' comments regarding their highly innovative project, which was technologically superior not only to those of their competitors, but also to the prototype that had been designed by industry specialists.

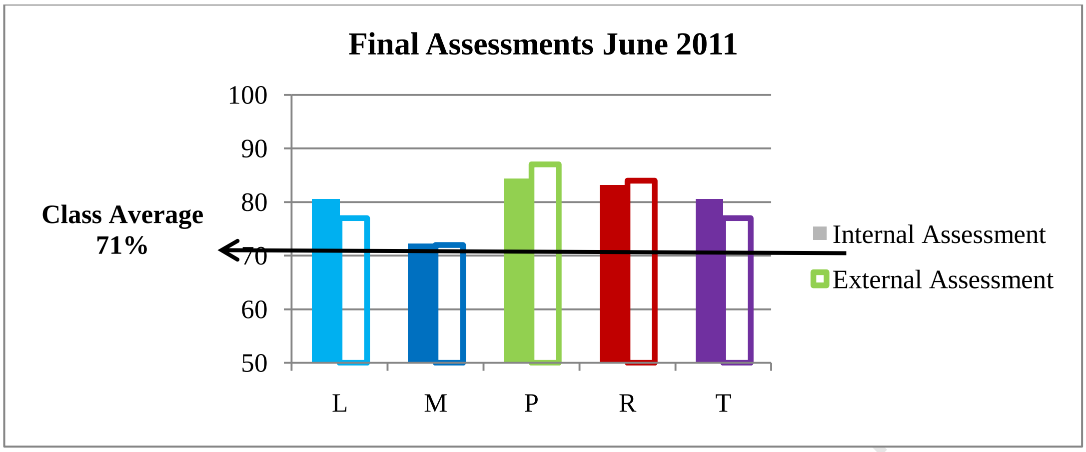

Figure 19 Assessment of 'output'

6.3 Answering the research questions

In order to answer the five sub-questions, I will be referring to the graph below (Figure 20), which encapsulates the group interviews (excluding student M)[23]. The graph represents the discussion of key problems and solutions that, effectively speaking, would sequentially summarise the design process of the mechatronic system under construction.

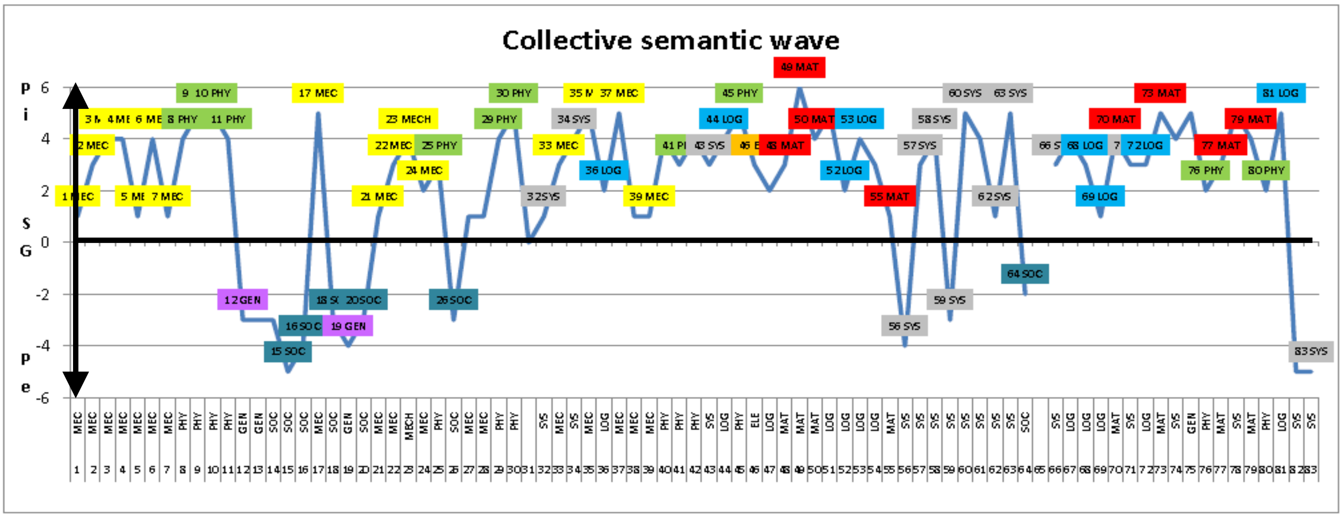

Figure 20 Collective semantic wave

[23] Student M was engaged in an alternative project, but had been selected as the 'logistics' member of the team. He did not, therefore, contribute to the technical problem solving process which was the focus of the interviews. His inclusion in this study however is precisely to demonstrate the validity of his inclusion on the team as a result of his way of working with knowledge.

6.3.1 What does 'integrate and apply knowledge' mean in this context?

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[24]. Over time, however, they merge into a 'system'. One can see this develop in Figure 20, where from turn 57 onwards, just after the halfway mark, there are increasing references to the 'system'. Likewise, the conceptual disciplinary core of these (physics, mathematics and logic) merges into 'control', broadly labelled in the graph as 'logic'.

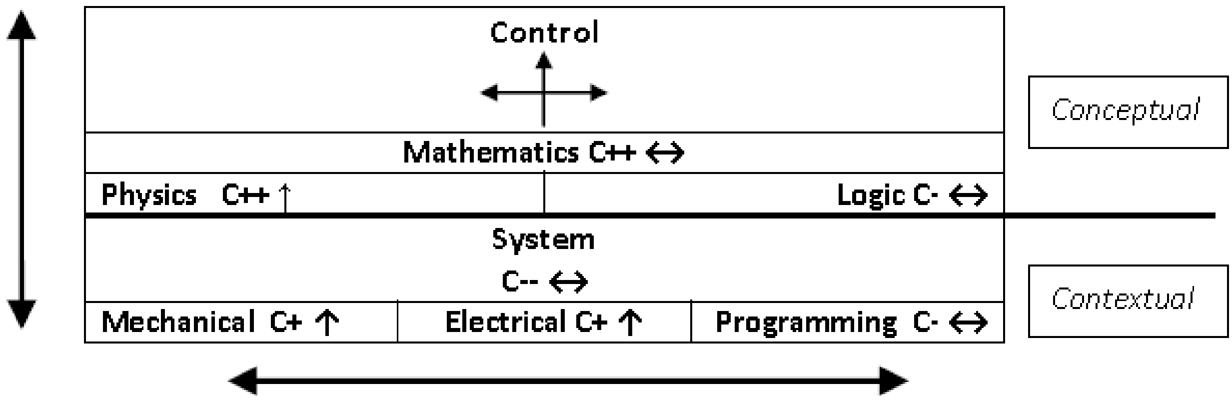

Figure 21 Mechatronics knowledge levels

As the design process develops, it becomes increasingly difficult to isolate those elements in the lower part of Figure 21. However, the more complex the problem in the 'system', the more important it seems 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'. Ideally, therefore, integrating and applying knowledge in this region is the ability to move along the two axes in Figure 21 simultaneously. Only two students in the case study (P and R) were explicitly able to identify the specific disciplinary focus of a problem. The collective outputs, however, were assessed in such a manner that suggests that all these students were capable of integrating the required knowledge. I suggest that for M, L and T, the integration process is at a tacit level, requiring more time for trial and error type practices, and is more dependent on situated and experiential knowledge.

[24] Elaboration on the electrical engineering elements, however, were not facilitated by the particular focus of the interviews. These would have been covered during the earlier structural design phase. See Appendix F for an industry generated mechatronics design process which confirms my sequencing statement.

6.3.2 What kind of knowledge is available to the student and how is it perceived?

It is clear from the preceding description that the key knowledge types relevant to the region and its practice are available to these students, but that only two students are able to explicitly identify the core disciplinary knowledge of physics and mathematics at a conceptual level, particularly in the face of problem solving. Problems of this nature for M, T and L are described in broader regional/curricular terms as mechanical, electrical or programming. However, what drew my attention was their frequent references to and apparent dependence on practices 'below the line', those which I have termed praxis external to the object/system. What exactly are these practices?

Although Bernstein defines horizontal discourse as 'everyday' knowledge, the principles underpinning his definition of individual *repertoires* as "a set of strategies" that enables the individual to function in different social or practical contexts (2000, p. 159) would be applicable to many of the practices external to the object/system. The 'professional' practices include activities such as completing documentation, drawing up budgets, making phone calls, correspondence, running meetings, and attending interviews. They are a fundamental part of the student's training in preparation for WPL, and are informed by the student's individual 'social' *repertoire* as well as the only explicit pedagogic relationship experienced by the students in the fifth semester: their relationship with me as the Engineering Professional Studies (EPS) lecturer. My close relationship with industry partners who facilitate student training has meant the development of an acute awareness of the importance of the "attitudes, aptitudes and dispositions"[25], which Maton has termed a *knower code* (2009, p. 46). The 'professional practices' with which the students engage are 'modelled' to an extent on my own rather Germanic focus on 'precision', and speak to what Bernstein terms the 'regulative discourse': "the moral discourse which creates order, relations and identity" (2000, p. 32). Although these practices are modelled in a critical paradigm,[26] I suggest they bear a close resemblance to the practices Gamble describes in reference to craft pedagogy where the "substance of regulative discourse [...] relates to a secular notion of work ethic" (2010, p. 132). Furthermore, as Gamble too has suggested, the regulative here may well mediate "a move towards an orientation to meaning that can entertain distance and objectivity beyond the immediate moment" (ibid., p. 138). As their lecturer, my intention is to facilitate an orientation to meaning that sees all the requisite knowledge practices as part of a greater 'system' (a complex system such as that which describes the emerging region itself), and a system in which attention to detail and precision (which characterise the nature of the regulative discourse here) are fundamental, given that human lives are at stake in all engineering endeavours.

The semantic waves presented in this research clearly demonstrate that problems are being solved by drawing not only on disciplinary/regional knowledge typical of vertical discourse, but also on practices associated with horizontal discourse. The key technological innovation that won these

[25] Indeed, a previous study as part of my coursework component for this qualification revealed industry assessors placed greater emphasis on *knower* attributes than knowledge.

[26] The practices are made explicit, and the implications for power relations are openly discussed as a means to empower students entering WPL.

students top prize in an international competition was the use of the one-way bearing, as described in the first interview. Identifying the possibility of this component came from experiential knowledge of a sporting activity by student T; sourcing the component (student R) was dependent on knowledge of ways in which to access that information (ICT engagement); actually purchasing the component (student L) meant making business calls, applying budgetary decisions, writing correspondence and negotiating with a range of people. These are context-dependent practices without which the integration of this key component into the system would have been impossible (as the component had not been supplied as part of the equipment). Without this component, the students would not have engaged with the complex method of control thus required. Without the logistical support of student M, they would not have been able to attend the competition. They would not have won this competition and been able to showcase their technological innovation without drawing on their individual *repertoires* of both social and non-disciplinary 'professional' practices.

6.3.3 What are the procedures the student follows in applying this knowledge?

Over and above the sequencing through mechanical, electrical and programming aspects, and the movement along the vertical knowledge axis as illustrated in Figure 21, the 'one-way bearing sourcing' example is already an indication of a 'procedure' in integrating multidisciplinary knowledge. Yet another procedure emerges in the set of practices 'below the line' termed 'social'. What became apparent during the course of this research was that though academic and industrial texts (evidencing relatively strong semantic gravity) initiate the process of engagement with knowledge in the context of application, the moment students are 'stuck', they consult alternative forms of 'text': each other, a lecturer, or ultimately, the primary source of 'new' or 'unpedagogised' knowledge in this region, namely, the invisible community of users present in the ubiquitous technology fora on the Internet. These user-fora could be described using Bernstein's definition of *'reservoir'*, "the total sets [of repertoires] and its potential of the community as a whole" [to make meaning in practical contexts] (2000, p. 158). I would like to suggest that Bernstein's original conceptualisation of reservoirs of everyday knowledge has been super-ceded by the IT revolution. The lack of restriction offered by the Internet means the exponential potential in exchange of a range of repertoires and the development of a collective reservoir in which the boundaries between the traditional vertical and horizontal discourses are beginning to be blurred.

6.3.4 What enables the student to integrate the knowledge effectively?

Access to this collective reservoir, given the implications of the potential shift in power away from both the Official and Pedagogic Recontextualising Fields, needs to be sanctioned. The learning paradigm underpinning the WIL semester (and indeed the programme as a whole) is one in which such access is actively encouraged, thereby granting the students greater agency. Salomon and Perkins, elaborating on the use of ICTs to facilitate learning, refer to the 'culture' of a learning environment. "The acquisition of knowledge is [...] a matter of the learner's active engagement in

[...] constructing knowledge out of the raw materials of experience and provided information" (1996, p. 5). They highlight 'understanding as a network' and the significance of 'social interaction' and 'distribution' of knowledge. "Achievements are jointly constructed in a social system, aided by cultural tools" (ibid., p. 10). My observation of the project group was that the 'integration of knowledge' was facilitated by the immediate social system (peers), and the broader social system (collective reservoir of users). Salomon and Perkins emphasise the 'situated', 'generalised' and 'self-regulated' principles of learning (1996). These are evident in the flexible approach to space and time during the WIL semester, a learning paradigm which enables engagement with "tasks that reflect the realities of practices in ... everyday contexts and that allow them access to the knowledge of experts with experience of relevant real-world practices" (Maton K. , 2009, p. 47). That this 'expertise' lies in an invisible community of practice may have profound implications for the nature of agency in the various fields.

6.3.5 What does the student's integration process tell us about the way this kind of knowledge works?

I suggest 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), which is contextual, to the 'integrated system', which includes the invisible dimension of the embedded system (programming language). Each of the *contextual* aspects can further be interpreted as vertically *conceptual* as they entail the 'invisible' core disciplinary features of 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.

The findings suggest that the ability to 'see' the system as a whole and yet identify, when necessary, the parts and their micro connections is echoed in the students' ability to draw on other systems. Students M, L and T tend to articulate their understanding of systems based on more context-dependent practices with which they are familiar, suggesting a 'form of cumulative learning' Maton describes as based on "students' habituses rather than explicitly articulated procedures" (2009, p. 58). Their specific functions on the project also appeared to be supported by how the knowledge itself shaped their practice. Student M, in this context, was required to support the project through logistics and marketing, fundamentally context-dependent practices, and through which very practices he manages to access Mechatronics knowledge in his own project context. Students T and L tend to engage in trial and error applications until it 'feels' right, drawing on experiential knowledge, and were crucial to the early 'trial and error' conceptualisation of the project. 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 innovative problem solving. Both students P and R interpret the required knowledge in epistemic terms, and are able to articulate this at a higher level of abstraction, suggesting “the different orientations to meaning students bring with them to education” (Maton K. , 2009, p. 55).

The implications for the emerging region are that though the dichotomous knowledge typologies fulfil a descriptive function, aiding in the understanding of the different ways in which the different types of knowledge may be acquired, the region is defined through praxis and not curriculum structure. The praxis that emerges suggests the need to understand the epistemic base as a synthesis of separate knowledge forms, as well as the imperative to make explicit both the independent nature of and relationship between the different forms of knowledge at the level of *concept* and *context*.

Chapter 7. Conclusion

This research project 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 the curriculum design and qualification types to be proposed according to guidelines set out by the HEQF (2007). Having established the complexity of multidisciplinary engineering curricula as a result of multiple recontextualisation processes and stakeholder involvement, it was suggested that evidence of knowledge integration problems in the region (Bailey McEwan, 2009; Bishop, 2002; Shooter & McNeil, 2002) may be the result of underestimating three factors:

- the dichotomous nature of the underlying knowledge structures
- the disjuncture between the assumed theoretical foundations and the field of praxis
- the nature and degree of conceptuality required to integrate Mechatronics knowledge

Drawing on the conceptual tools of Basil Bernstein and his followers, an in depth analysis of the current curriculum revealed that there are distinctly different knowledge structures underpinning the region, each of which has different implications for *conceptual* grasp. The hierarchically structured physics-based subjects, together with horizontally structured mathematics, form 50% of the current curriculum. Physics requires a long induction period (which begins in primary schooling) with knowledge progressing upward to form increasingly subsumptive abstract principles. A good foundation in physics can enable the principles introduced in HE to be grasped in an instant. Horizontal knowledge structures, on the other hand, require the accumulation over time of different segments, most of which in this context (barring mathematics) are entirely new types of knowledge, only introduced in HE and predominantly application-specific (the remaining 50% of the curriculum). This suggests the need for extended periods of time accumulating “masses of particulars” (Muller, 2008, p. 15).

By using Karl Maton’s concept of semantic gravity (2009), which was developed as a move away from the dichotomous view of knowledge structures, the analysis of student practice was intended to accomplish two things: on the one hand, it offered a tool through which to examine the different types of knowledge on which the students drew, and on the other hand, it revealed the movement up and down a context-dependency scale, as an indication of the degree of verticality in the student’s actual practice despite the type of knowledge. This analysis revealed that the knowledge implicated in the region cannot be dichotomised in a collection-type curriculum (strongly classified ‘subjects’), and that the two knowledge structure types operate symbiotically, suggesting a third form, one I have termed a *dynamic bi-axial knowledge structure*. What appeared clear from the analysis was the difference in weighting of the two separate knowledge structure types 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 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 also highlight the significance of generic practices (many of which could be characterised as having the features of horizontal discourse) in enabling integration of knowledge in practice. The limitations of this dissertation, however, have not allowed as full an investigation as desired, and I believe this warrants further investigation. Furthermore, the increasing reliance on specialised knowledge situated outside the academy (community of practice 'reservoir') suggests this needs to be considered in curriculum design (and pedagogy), as well as in the nature of the qualification.

The findings here (albeit a very small sample) appear to suggest the feasibility of two potential qualification levels. The current predominantly *contextual* curriculum at Diploma level may facilitate the integration and application of different forms of knowledge through exposure and access to contextual opportunities in which the *conceptual* is tacitly grasped through trial and error, and supported by access to socially-situated knowledge. However, the results of the analysis also suggest that a more complex knowledge structure may characterise this emerging multidisciplinary region, requiring a different praxis capability: the ability to appropriately access relevant theory from the core disciplines (the 'know-why') and procedural 'know-how' from the reservoir of practitioners, and to integrate this in a particular context of application. Despite the current contextual curriculum, there are students who evidence this capability and who effectively engage in the more 'broadly-defined' problems characterising a higher qualification, such as the envisaged Bachelor of Engineering Technology. The relationship between 'the structuring of knowledge' (Maton & Muller, 2006) and praxis appears to be symbiotic, although it is not clear which direction this relationship takes. This limited research sample suggests the student approaches the knowledge via systems already encountered and accessible, as opposed to the knowledge forms themselves driving integration. It is my belief that this warrants further research.

A further issue that emerges as warranting investigation is the absence of correlation between mathematics assessment results and the degree of actual mathematical engagement with problems in relation to the 'logic' underpinning control systems. The inability to recognise the mathematics and physics principles (crucial for solving multidisciplinary problems of system control) may be as a result of the strongly classified nature of these subjects in the current curriculum as well as the underlying structures not being compatible with the actual 'integrated' logic of the region. It may be worthwhile to re-examine the way these subjects are curriculated in order to make more explicit the relationships of the core disciplines to each other and to the 'system' as a whole. This could provide the very 'relational idea' Bernstein describes as crucial to integrated regions (1975, p. 83), and one which could be the basis of a coherent regional theory.

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Appendix A Extract from ESGB: Diploma

Engineering Standards Generating Body

HEQF-COMPLIANT GENERIC ENGINEERING QUALIFICATIONS: Diploma

FIELD: Manufacturing, Engineering and Technology

SUBFIELD: Engineering and Related Design

NQF LEVEL: 6

Minimum Total Credits: 360
Minimum Credits at Exit Level: 120
Minimum Credits at Level 7: 60

...

The particular engineering learner completing this qualification will be competent and able to display the following learning outcomes on:

1. −Solving well defined engineering problems.
2. −Applying of scientific and engineering knowledge.
3. −Performing engineering designs.
4. −Conduct investigations, experiments and collate data analysis.
5. −Using appropriate engineering methods, skills and tools, including the use of Information Technology.
6. −Communicating technical information in a professional manner.
7. −Demonstrating critical awareness of the impact of the engineering activity.
8. −Effectively working as an individuals and in teams
9. −Engaging in independent learning.
10. −Acting professionally and ethically at all times.

New: [Engaging in engineering practice via work integrated learning.]

Appendix B1 'Knowledge Map' instructions

STUDENT:	DATE: 17 March 2011

Dear MIJ130M students

In order to prepare you for the interview process where many companies may face you with technology and ask you to demonstrate what you know, I would like you to prepare by spending time in the lab doing the following exercises. Firstly by hand, on the A3 sheet provided, sketch out the station areas, as well as a space for EPS and Design, and using a mind map type format, add the following information:

1. Go to each station you have already completed and the ones you have not, and see if you can name all the components and subsystems
2. Then try to identify what 'knowledge' you needed to understand what the station is about and to make it function effectively
    a. Did you need 'subject' knowledge? If so, indicate which subject and what aspect. (See overleaf for a list of your S1 to S4 subjects)
    b. Did you need previous experience? Where did you get this experience?
    c. Did you teach yourself? How? From where?
3. When you have completed the A3 hand-drawn sheet, transfer the information to the form below, save as MIJ130A Knowledge Map SURNAME, and email it to me at wolff.ke@gmail.com

Appendix B2 Student Profiles & Findings

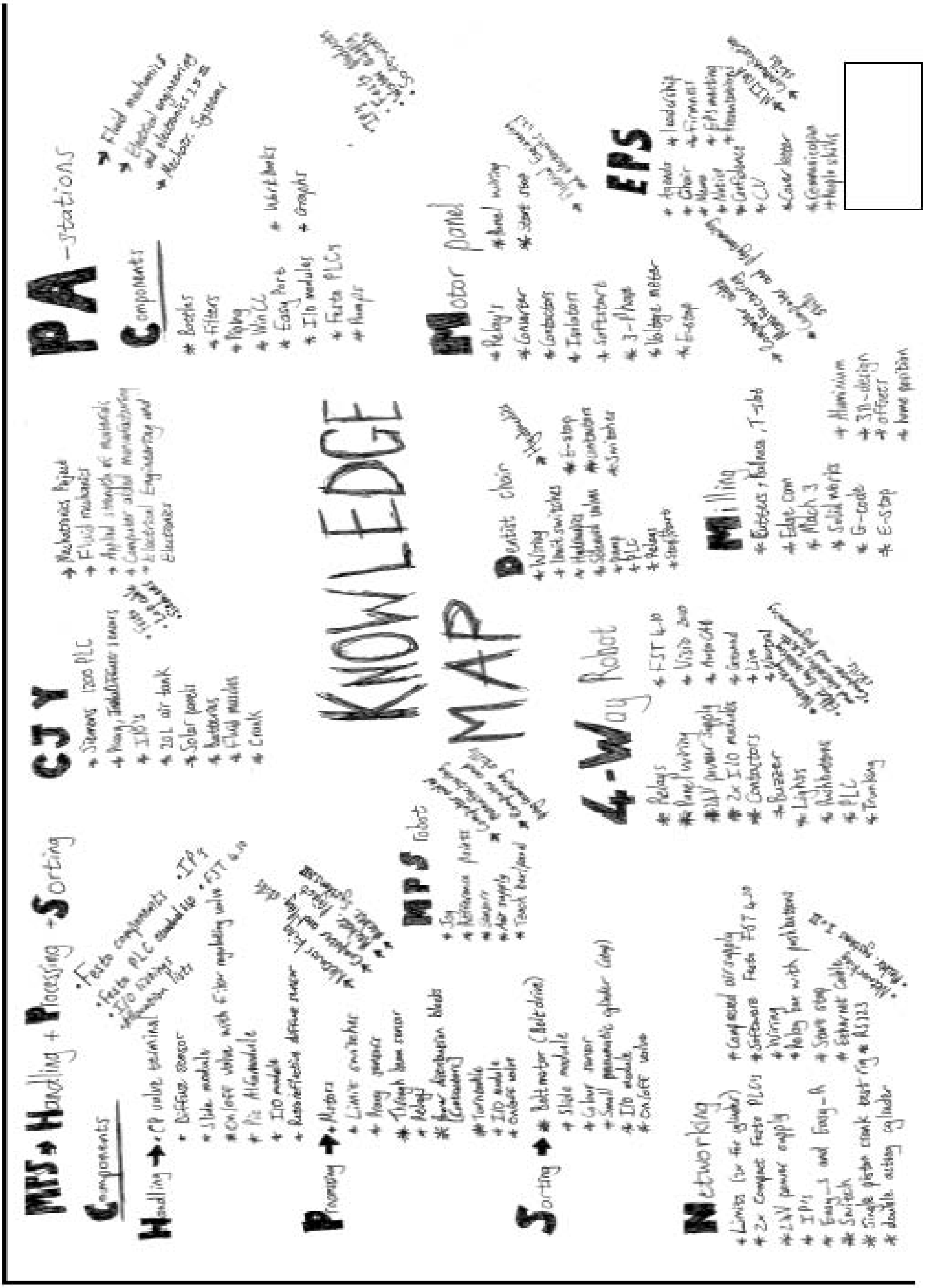
STUDENT	AGE	1ST LANG	MED INSTR	OTHER	SCHOOL	ORIGIN	WORK EXPERIENCE	HE Academic Record					Semantic Wave Range Time sheet	Disciplinary Abstraction	Predominant explicit knowledge
								MAT	PHY	LOG	TECH	GEN			
L	21	Afrik.	Afri	Eng	State	SA	1-year intern Automotive	59	60	71	84	74	Pi4 to Pe-5	Pi 4 = Mech/ Elec	Mech/ Gen(-5) / Social
M	21	Xhosa	Eng	Zulu	Maths & Science College	SA	Media technician (part-time)	59	67	67	78	67	Pi4 to Pe-4	Pi5 = Mech	Mech/ Logic/ Gen (-5) / Social
P	26	Eng.	Eng	None	State	Europe	4 years general engineering environment	57	69	85	89	82	Pi5 to Pe-4	Pi 6 = Mat/ Phy Pi 5 = Log/ Mech	Math/ Phy/ Log/ Gen
R	20	Ger	Ger	Eng/ Afri	Private	Africa	4 years holiday work - maintenance & programming	63	77	78	88	78	Pi4 to Pe-4	Pi 6 = Mat/ Log Pi 5 = Phy/ Gen/ Sys	Math/ Phy/ Log/ Gen
T	29	Afrik.	Afri	Eng	State	SA	4 years motor industry	55	62	68	80	76	Pi4 to Pe-4	Pi 5 = Mech Pi 4 = Elec/ Log	Mech/ Logic/ Soc(-5)

* Distinctions highlighted

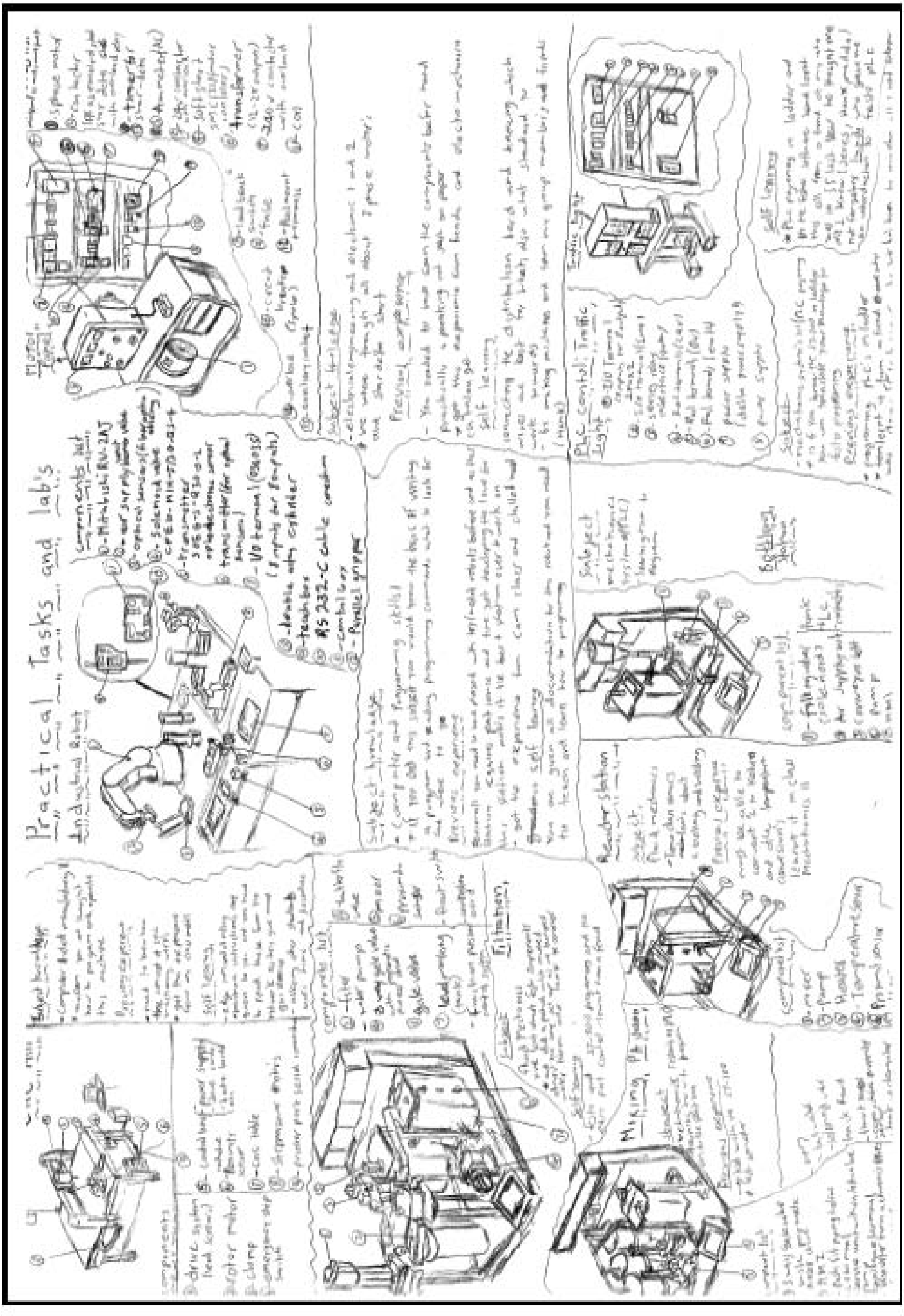
Appendix C1 Knowledge Map analysis

KNOWLEDGE MAP ANALYSIS		DISCIPLINARY REFERENCES			CURRICULUM REFERENCES			PRAXIS - internal		PRAXIS - external	
STUDENT	MAP STYLE	MAT	PHYSICS	LOGIC (PROG/ NET)	C+ SUBJECTS	C- SYSTEMS SUBJECTS	APPLIED SUBJECTS	PRIOR PRACTICAL EXPERIENCE	PRIOR THEORETICAL EXPERIENCE (heard/seen/ sourced)	GENERIC ENGINEERING	GAs
M	1	0	2	0	1	1	1	1	3	-2	-5
M	Object-orientated; graphic; labelled & numbered (as per technical diagrams); Systematic, procedural; many full sentences	X	FLUID MECHANICS THEORY; THERMO,		MECHANICS, ELECTRICAL	MECT SYS, PROG	CAM, CAD	Many references to previous academic practicals	many references to learning from peers; docu sources, childhood; 'play with robots'	ordering, cleaning, administration, aesthetics	patience, love for a subject, ethics, project planning, group work, independent learning
R	3	5	5	6	0	1	1	2	2	-3	-3
R	CONCEPTUAL, RADIAL, KNOWL & COMPONENTS INTEGRATED IN PLACES	ALGEBRA (re PID control) X 2	FLUID FLOW THEORY, TORQUE, BEHAVIOUR OF AIR IN PNEU SYS, POWER TRANSMISSION	"PROACTIVE SYSTEM DESIGN", NETWORKING, IP ADDRESSING, COORDINATE SYSTEMS; "Logical thinking to keep track of program cycle"; "sending & receiving memory data"	X	MECT SYS, PROG	CAM, CAD	X (Notes that for all, Computer literacy is required)	X (Notes that for all, Computer literacy is required)	computer literacy, fault-finding, safety, standards	organisational skills, time man.,leadership, confidence, 'selling yourself'
P	2	0	3	3	0	0	0	0	0	-3	-2
P	CONCEPTUAL, RADIAL, KNOWL & COMPONENTS SEPARATED, PLANNED: ALL STATIONS FIT ONTO ONE SHEET	X	DIMENSIONING, THERMODYNAMICS, FLUID DYNAMICS,	PNEU SYS, FLOW SYS, FLOW CONTROL, NETWORKING, DIGITAL THEORY	X			X	X	Process management, debugging & error-checking; problem-solving	organisation, communication skills
T	2	1	2	2	1	1	1	0	0	-2	-2
T	MIXED, GRAPHIC OBJECT/CONCEPTUAL, UNPLANNED	MATHS FOR 'TIMING' & 'WORKING OUT…'	FLUIDS - FLOW CONTROL X1	COORDINATE SYSTEMS	DISCIPLINES: MECH/ & ELECTRICAL X 1	MECT SYS, PROG	CAM, CAD	X	X	Building the design	Communication
L	2	0	2	2	1	1	1	0	0	0	-3
L	VERBAL, VISUAL, SYSTEMATIC, OWN CONSISTENT CODING		FLUID MECANICS, HYDRAULICS	NETWORKING	ELE ENG & ELECTRONICS	MECT SYS, PROG	CAM, CAD	X	X	X	leadership, firmness, presentations, people skills

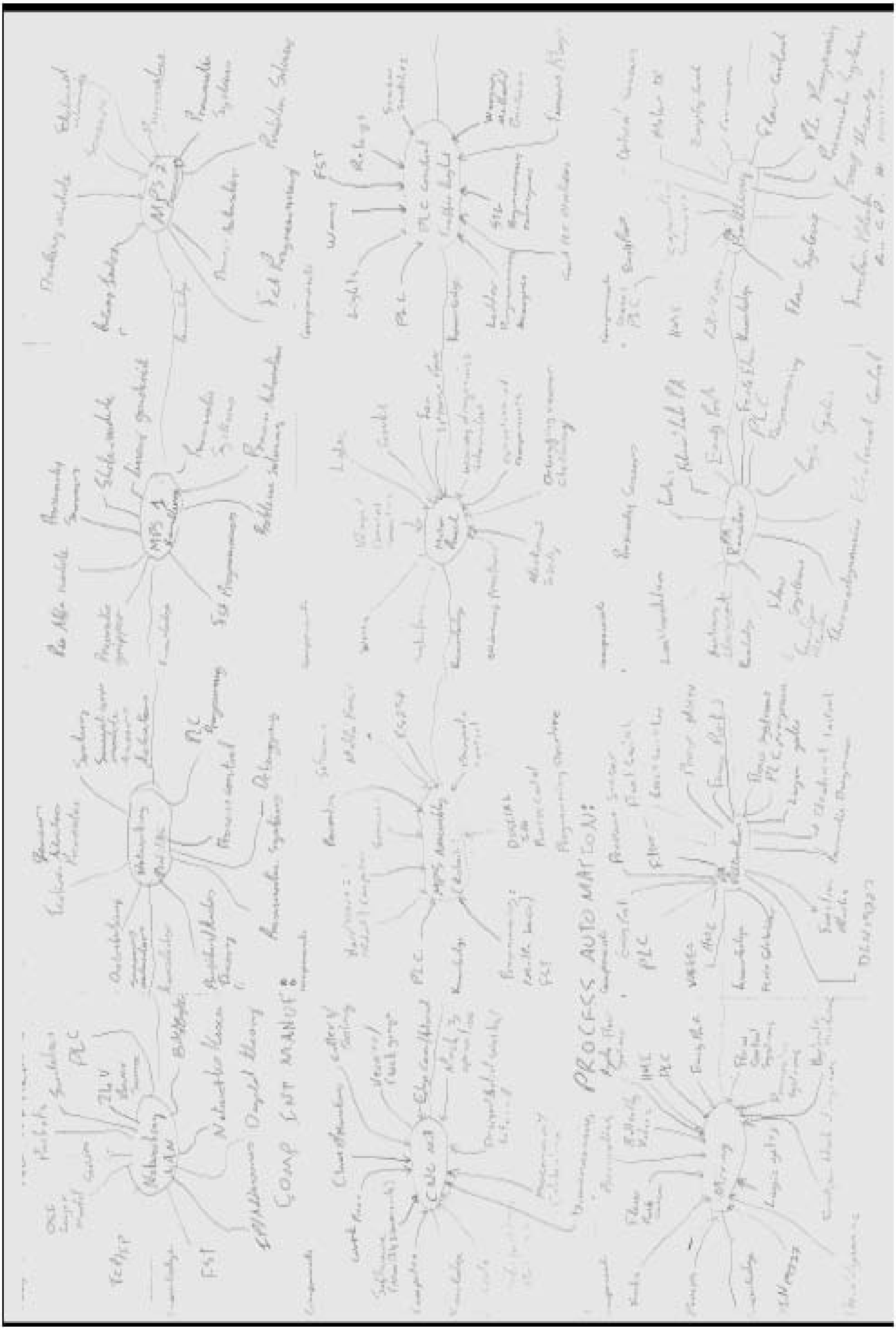
Appendix C2 Student L Knowledge Map



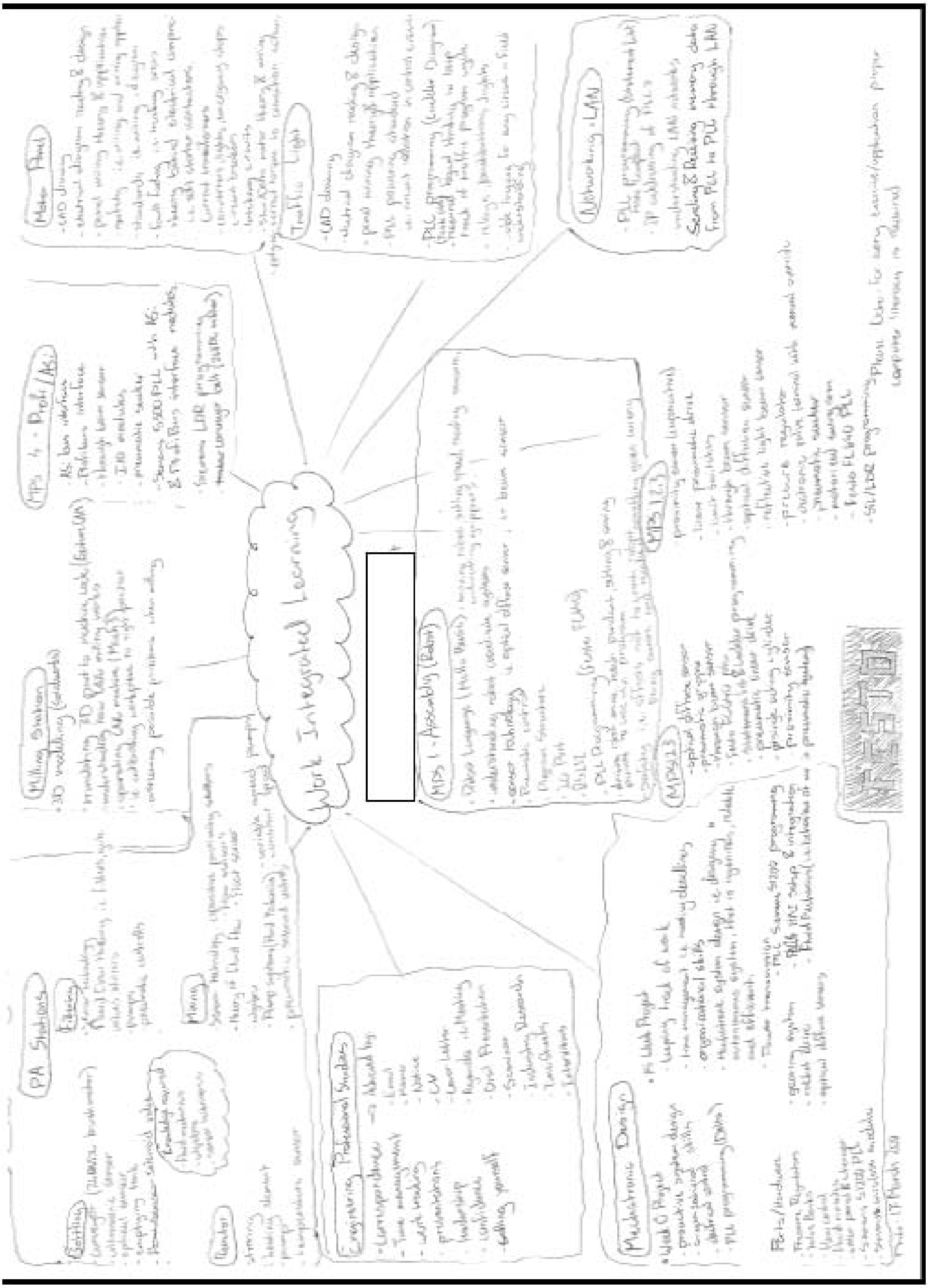
Appendix C3 Student M Knowledge Map



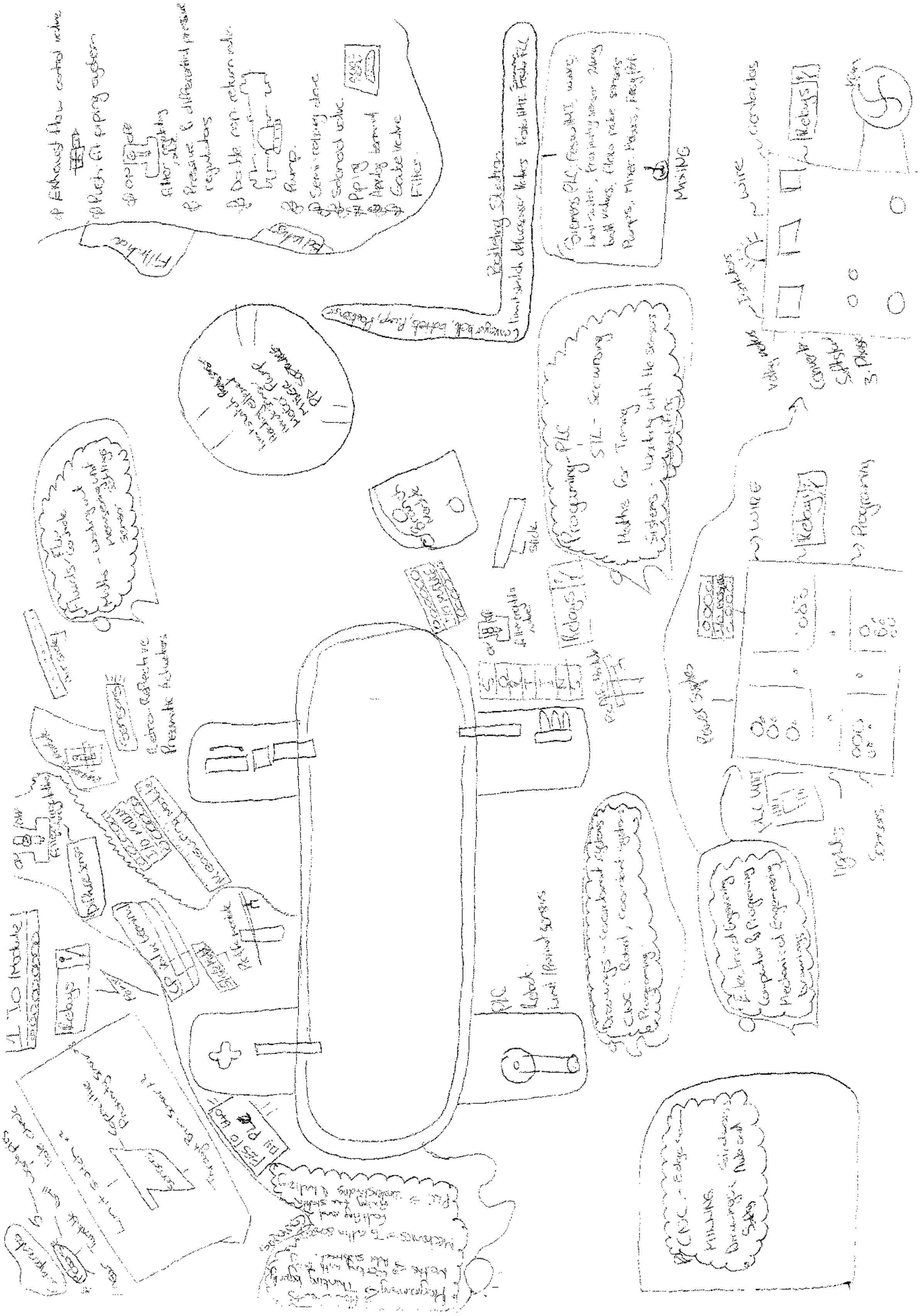
Appendix C4 Student P Knowledge Map



Appendix C5 Student R Knowledge Map



Appendix C6 Student T Knowledge Map



Appendix D1 Student M Time sheet analysis

Student M TS **Monday**	MON	KNOW	Value Pi/Pe	CODING Pi	CODING Pe	
busy with bottling station connection.	8	LOG	2	Summary: Object-orientated		
ask for help from mr marais on the connection of the HMI program error, which he finally show us how he did is own, when working on the bottling station.	9	LOG	-3		Interpretation: Identified problem	COP peers
start with the exercise as stated in the workbook in other to achieve the aim.	10	LOG	-1		Reproductive: object-orientated academic process	
still busy with bottling station programming exercise , we finish with the first one and move to the secongd program.	11	LOG	1	Reproductive: object-orientated practical process		
went to makes call to the companies(RS component,ELEtroMECanical,cnc direct) we gonna be getting our quotation for coupling and mach 3 board, from them.	12	GEN	-1		Reproductive: practical process	prof-prac
lunch	13	SOC	-1		Reproductive: practical process	social
me and mr s---i quickly had a meeting with mr --- quotaton and specification for the mach3 board we get the invoice.	14	LOG	4	Judgement: making a decision that affects working process (I know they demonstrated how they intend to use the Mach3, in order to get approval)		prof-prac
Went to the chemist to get something for my flue and was kindly assisted I was so seek that my mind could not think straight and i had to live early to go and sleep so as to get better	15	SOC	-2		Summary: SOC process	social
sleeping	16	SOC	-1		Reproductive: practical process	social
Tuesday	TUE		0			
Waited in the car as we had arrived earl for S---- interview . Went to the interview at 8:50 waited for my turn to be interviewed which began at 9:15	8	SOC	-1		Reproductive: practical process	social
Interview bean and i was asked basic question to find out what i had learnt at school and answer.		GEN	-2		Summary: SOC process	prof-prac
I enjoyed the interview as both the guys that interviewed me and answered every question confidently. I enjoyed the interview as both interviewers have seen and experienced where i grew up as it is close to hole in the wall.	9	GEN	-3		Interpretation: Personal significance	prof-prac
At 10:00 we got taken around the company yet where not allowed around for long and and the interview ended at 10:20	10	GEN	-2		Summary: SOC process	prof-prac
We then made our way back to cput arrived at tech at 11:15 and i went to my room to change my cloths and get my books	11	SOC	-1		Reproductive: practical process	social
Got back to class and found out what they did. Sat in for T--- short presentation of what to expect in industry and how to conduct your self.		GEN	-2		Summary: SOC process	COP peers
As he explained that you nee to get used to reading manuals and doing things you self yet if you need help don't be afraid to ask yet be considerate of others	12	GEN	-3		Interpretation: Personal significance	prof-prac
Went on the RS components cataLOGue and started looking for a contact we needed for welding robot project .found one at 1:30 on page 237. at 1:40 i then when to make a call to RS components	13	GEN	1	Reproductive: object-orientated practical process		COP
Went to see Mr H--- as he had a concern about where we are going to be working me and S---. He expressed this concern about where we going to work asking question on what we like and love to do he said lets tell	14	SOC	-3		Interpretation: Personal significance	*social*

him what we want to do for in-service training do we want to work						
continued discussion wit Mr H---	15	SOC	-2		Summary: SOC process	social
updated project note book	16	GEN	-2		Summary: practical process (includes GENeric admin)	prof-prac
did networking report	17	LOG	2	Summary: Object-orientated (technical report)		
Wednesday	WED		0			
Helped Mr P---t to mount the projector screen to help with the prisentation	8	GEN	-2		Summary: practical process (GENeric)	prof-prac
Prepared the presentation for the first Group. And they began, waterless lan Bluetooth	9	LOG	-2		Summary: practical process (GENeric)	prof-prac
presentend on infrared SYStems had a braeck at 11:00	10	LOG	-2		Summary: practical process (GENeric)	prof-prac
HSPA / HSUPA high speed packet access ,GSM structure . 12:00 began RC controller presentation	11	LOG	2	Summary: technical content		
Downloaded flow stone.	12	LOG	2	Summary: technical process		
mad sure that Mr M--- JG had pt in the RS component and quotation i requested		GEN	-2		Summary: practical process (GENeric)	prof-prac
Connected the welding robot control programmable board via hyper terminal to see if the motors have reached there limits	13	LOG	1	Reproductive: object-orientated practical process		
Spoke to Sergio Andre on how to write software and		LOG	-3		Interpretation: Identified problem	COP peers
what do i need to know to hijack the SYStem software to make it do what i want t to do	14	LOG	3	Interpretation: identifying technical problem		
Continued with Sansui and Sergio Andre and draw a conclusion on what needs to be done	15	LOG	-2		Summary: SOC process (though refers to 'drawing conclusion, does not specify)	COP peers
Took a look at the washing machine project and wiring also connected it to the plc to do the functions we required	16	LOG	2	Summary: technical process		
Thursday	THU		0			
got my lap top ready and checed my mail.meeting started by Sheldon	8	GEN	-1		Reproductive: practical process	prof-prac
Meeting ended and lunch for 15min ??		GEN	-1		Reproductive: practical process	prof-prac
downloded cnc program	9	LOG	2	Summary: technical process		
Safety seminar began and video began to make use awe	10	GEN	-2		Summary: practical process (GENeric)	prof-prac
Safety awareness campiness continued with the class interaction at 12:15 Safety seminar ended	11	GEN	-2		Summary: practical process (GENeric)	prof-prac
Manufacturing seminar began as they looked as a companies that we would go into as this is a big and broad concept Seminar ended at 1:07	12	GEN	-3		Interpretation: Personal significance	prof-prac
10mints lunch and At 1:55 we started with Ms Wolff giving an update on the job application process	13	GEN	-2		Summary: practical process (GENeric)	prof-prac
Arranged and asked Ms Wolff permeation to call Ryan at SPT	14	GEN	-1		Reproductive: practical process	prof-prac
Downloaded the Mach 3 software	15	LOG	2	Summary: technical process		
I received a call from a company in Canada regarding CNC control software.		GEN	-2		Summary: practical process (GENeric)	prof-prac
They where very help full and continued to promise to email me more inforMATion	16	GEN	-3		Interpretation: Personal significance	prof-prac
Friday	FRI		0			

set up computer use the cnc software	8	LOG	1	Reproductive: object-orientated practical process		
I had downloaded over night G- code translator , and cnc usb controller .		LOG	2	Summary: technical process		
but had a problem with my usb port and my pc so i had to fix this before the RS 232 cable could be used	9	LOG	3	Interpretation: identifying technical problem		
Started solving the challenge with my pc windows not working buy installing drives Began working on the PA station HMI with Marais JG for the reactor station	10	LOG	4	Judgement: making a decision that affects working process		
Tutoring solid works in the drawing class	11	GEN	-2		Summary: practical process (GENeric)	COP peers
Tutoring solid works in the drawing class	12	GEN	-2		Summary: practical process (GENeric)	COP peers
Tutoring solid works in the drawing class	13	GEN	-2		Summary: practical process (GENeric)	COP peers
Tutoring solid works in the drawing class and ended	14	GEN	-2		Summary: practical process (GENeric)	COP peers
Sat with Sanusi,Jires, and conclude on which software works and what we will do over the week end	15	LOG	-4		Interpretation: Identified problem/Judgement: decision	COP peers
updated time sheet	16	GEN	-2		Summary: practical process (includes GENeric admin)	prof-prac

Appendix D 2 Student L Time sheet analysis

Student L TS						
Monday	MON			Pi/Pe		HORIZONTAL - TYPE
Weekend was a bit too nice so I quicly had to do my timesheet for the previous week	8	SOC		-3	Interpretation: Personal significance	PROF-PRAC
Myself and Mr. T--- proceded to do the motor panel, we took off all the wires of the previous groups work and proceded with Nr. 1.	9	ELE	Reproductive: object-orientated practical process	1		
As I never had done panel wiring before I was a little nervious at first.	10	SOC		-3	Interpretation: Personal significance	SOCIAL
We completed nr. 1 in only a few minutes	11	ELE	Summary: practical process (technical topic identified	2		
but struggled a little bit more with nr. 2 and nr. 3.		ELE	Interpretation: technical problem	3		
Mr van Wyk was very helpful in answering our questions and helping us here	12	ELE		-4	Judgement: decided to ask for help (peer) and then applied what they learnt	RES/PEERS
and there. We managed to finish nr. 3 so that it could get marked the next morning. Myself and	13	ELE	Summary: practical process	2		
mr. Theron then proceded to finish our research regarding the MIJ130D presentation on wirELEss	14	LOG	Summary: practical process	2		
LAN. We got a nice amount of info to do our presentation on.	15	GEN		-3	Interpretation	PROF-PRAC
In the evening I also worked on the budget and letter for sponsorship for CPUT.		GEN		-2	Summary: practical process (GENeric)	PROF-PRAC
Tuesday	TUES			0		
Had some personal admin to attend to so I arrived at class a bit late.	8	GEN		-2	Summary: practical process (GENeric)	PROF-PRAC
Proceded in doing the previous days time sheet. Not in the mood to leave it until Friday again.	9	GEN		-4	Judgement: making a decision that affects working process	PROF-PRAC
Finalised the CJY budget, took it to Mr. H--- to inspect it before sending it to the dean,	10	GEN		-2	Summary: practical process (GENeric)	PROF-PRAC
had to make a few modifications on it.	11	GEN		-3	Interpretation: Practical significance modifications needed for budget	PROF-PRAC
Also our 3rd motor panel was marked and we proceded withexercise 4. It was marked at 1. We imediatelay proceded with nr. 5.		GEN		-2	Summary:process (academic)	
This proved to be the most difficult and took a lot of time	12	GEN		-3	Interpretation: Practical significance - time	PROF-PRAC
, since for some reason the fan started in in star, but didn't whant to switch to delta after the timer expired.	13	ELE	Interpretation: technical problem	3		
We later found out that it was a simple mistake on the small panel on the fan where the thick delta wires needed to be connected.	14	ELE	judgement: implies they made a decision to correct mistake	4		
We were now finished with the motor panel.	15	ELE	Interpretation: significance	3		
Also gave Mr. M---all the other files he needed from us.	16	GEN		-2	Summary: practical process (GENeric)	PROF-PRAC
Stayed up until the early hours of the morning to finish my part of the presentation on Wi-LAN for the next day.	17	GEN		-2	Summary: practical process (GENeric)	PROF-PRAC
Wednesday	WED			0		
We had a number of presentations to do regarding various types of wirELEss connections for today.	8	GEN		-2	Summary: practical process (GENeric)	PROF-PRAC
The presentations covered dail up, bluetooth, HSDPA and our topic, WirELEss LAN. Everything went really well.	9	GEN		-3	Interpretation: significance - 'Everything...' implies more than summary, that this was significant	PROF-PRAC
Found the others topics inforMATive and	10	GEN		-3	Interpretation: significance	PROF-PRAC

interesting. We focussed mainly on the					-	
technical side, so it took a lot of understanding of our topic before presenting it.	11	LOG	Interpretation: identifying technical significance	3		
break	12			-1		
Showed the modifeid CJY budget to my other team MATes and mailed it to Mr. H--.	13	GEN		-2	Summary: practical process (GENeric)	PROF-PRAC
lunch	14			-1		SOCIAL
Started with the testrig for the the rachet and gearing SYStem. We discussed some solutions	15	MEC	Interpretation: identifying technical problems	3		
for it but could not come to agreement on what would be best.		SOC		-3	Interpretation: significance -	RES/PEERS
We decided to then use the simplest method, welding a rod on the rachet we have	16	MEC	judgement: action decision	4		
and see if the muscle would be able to move the rached back and forwards a sufficient amount.		MEC	Interpretation: technical significance 'see if'	3		
Thursday	THURS			0		
Just waited for meting to start	8	GEN		-1	Reproductive: practical process	PROF-PRAC
EPS meeting led by Mr. S--- and Mr. B---.	9	GEN		-2	Summary: practical process (GENeric)	PROF-PRAC
Started with the Occupational Health and Safety seminar. Found it very interesting and enjoyed the way they let the class interact in it.	10	GEN		-3	Interpretation: personal significance	PROF-PRAC
Think it made everyone more aware of the dangers in class even though things may seem fine at first.	11	GEN		-5	GENeral conclusion: broader context (safety as a whole)	PROF-PRAC
The second was on manufacturing methods, felt it was more just a recap in all the machines and technoLOGies we used during the last few years here.	12	GEN		-3	Interpretation: significance	PROF-PRAC
lunch	13			-1	Reproductive: practical process	SOCIAL
Discussed and updated the interview and application file.	14	GEN		-2	Summary: practical process (GENeric)	PROF-PRAC
Discussed the situation with regarding T*** Finalised our interview date: 20th April 2011.	15	GEN		-4	Judgement: decision to take action - (called company, set up appoint)	PROF-PRAC
After this we further discussed the testrig for the CJY project. Ph---mentioned one way bearings used in RC cars.	16	SYS		-3	Interpretation: peer mentions alternative technology	RES/PEERS
We decided to go to Bearing man the next day and find out if the could supply is with it	17	GEN		-4	Judgement: decision to act based on problem	PROF-PRAC
because the rached was too rugged. The number of clicks was far too less for our application. Thus using the one way bearings, or even the internals of a rachet tool.		MEC	Interpretation: significance	3		
Friday	FRI			0		
Timesheet update	8	GEN		-2	Summary: practical process (GENeric)	PROF-PRAC
I started the day by roughtly designing and the building a test rig to test wether a rachet tool	9	MEC	Summary: practical process (technical)	2		
would work with the muscles. I struggled to remove the shaft and	10	MEC	Interpretation: technical problem	3		
went to the MECanical workshop to get help in removing it.	11	MEC	Judgement: decision to get help	4		RES/PEERS
Myself and T--- also went to Mr. Bearing to see if we could find the correct single way bearings.	12	GEN		-1	Reproductive: practical process	PROF-PRAC
Need to get shaft size and get back to them because it needs to be sent from JHB.	13	MAT	Interpretation: technical problem	-3	Interpretation: technical problem	
Ph--- will bring a few from his house. Continued in the rig. As soon	14	MEC		-4	Judgement: implies they decided to ask philip for help	RES/PEERS
as I mounted the rachet I realised that we would have same problem with it that we had	15	MEC	Interpretation: technical problem	3		

with the						
bicycle rachet. I told my fellow group members and scrapped the idea. Mr Hoffman added that	16	MEC	judgement: re technical solution	4		
we should firstly test the crank. I proceded in disasembling the previous rig.	17	MEC	Summary: practical process (technical)	2		
Assembled the crank and all its components, mounted it on a flat piece of wood.		MEC	Summary: practical process (technical)	2		
We can now connect the bycicle gearing and test it.		MEC	Judgement: / Interpr	3		

Appendix D 3 Student T Time sheet analysis

Student T TS						
Monday	Mon		Pi+/Pe-	0		HORIZONTAL - TYPE
Arrived at class	08:00		SOC	-1	Reproductive: practical process	SOCIAL
This week we started on the motor panel.		Reproductive: object-orientated practical process	ELE	1		
N1 one was fearly easy and the big wait was with mr m---	09:00		GEN	-3	Interpretation:	
Lucky for us he agreed to visit us regualry today even if it was not his day, I think he was in a very good mood	10:00		SOC	-3	Interpretation:	PROFPRAC
N1 was mark and continiud with nr2	11:00		GEN	-2	Summary: practical process (academic)	
n2 was mark continiud with nr3	12:00		GEN	-2	Summary: practical process (academic)	
Finished with nr3.	13:00		GEN	-2	Summary: practical process (academic)	
I started to finilize all my info on WLAN for our presentation on Wednesday. During my reserch I found a very good pdf.	14:00		LOG	-3	Interpretation: 'found ...'	PROFPRAC
Went home	15:00		SOC	-1	Reproductive: practical process	SOCIAL
Tuesday	Tues			0		
Aried at class	08:00		SOC	-1	Reproductive: practical process	SOCIAL
Calculations of cost WirELEss vs wired conections.	09:00		MAT	-2	Summary: practical process (GENeric)	PROFPRAC
Calculations of cost WirELEss vs wired conections.	10:00		MAT	-2	Summary: practical process (GENeric)	PROFPRAC
Went to Mr H--- to present our budget for CJY 2011. Got some interistimg feedback and how to chang it	11:00		GEN	-3	Interpretation: significance of 'feedback'	PROFPRAC
Motor pannel 3 was mark and we started with nr 4	12:00		GEN	-2	Summary: practical process (academic)	
Motor pannel 4 was mark and we started with nr 5	13:00		GEN	-2	Summary: practical process (academic)	
We encounter some problems with star delta. The star conection started but not delta.	14:00	Interpretation: technical problem	LOG	3		
after goinig threw the drawings we change the wiring and the motor pannal work.	15:00	Judgement: decision	ELE	4		
Mr M--- came to mark us but the drawings was incorrect and we needed to rewire it to correct the mistacks	16:00	Interpretation: technical problem	ELE	3		
Mr M--- came to mark us again in nr 5 and everyting was correct.			GEN	-3	Interpretation: significance	
we finalised our milling programs		Summary: technical process	LOG	2		
and ELEktrical drawing		Summary: technical process	ELE	2		
in a folder and handed it to Mr M--- for marking			GEN	-1	Reproductive: practical process	PROFPRAC
Wednesday	Wed			0		
Arrived	08:00		SOC	-1		SOCIAL
Group A Presentation. Dail up	09:00		GEN	-2	Summary: practical process (GENeric)	PROFPRAC
Group B Presentaition Bluetoot	10:00		GEN	-2	Summary: practical process (GENeric)	PROFPRAC
Group C Presentation me and mr L about WLAN	11:00		GEN	-2	Summary: practical process (GENeric)	PROFPRAC
Group E Presentation. Infrared	12:00		GEN	-2	Summary: practical process (GENeric)	PROFPRAC

Group F Presentation HSDPA	13:00		GEN	-2	Summary: practical process (GENeric)	PROFPRAC
Group G Presentation RC Control	14:00		GEN	-2	Summary: practical process (GENeric)	PROFPRAC
Went with Mr L--- to Mr H--- to present our budget for the CJY 2011 project.	15:00		GEN	-2	Summary: practical process (GENeric)	PROFPRAC
He help us with the final tutches and tolk us we need to get it as low to R50 000 if we think we will get extra money	16:00		GEN	-2	Summary: practical process (GENeric)	PROFPRAC
We also neede to give a more deatailed report for what we need it.			GEN	-3	Interpretation: significance - 'need to..'	PROFPRAC
After the budget speech my and mr L started with the tes rig for the CJY.		Summary: technical process	MEC	2		
After going thru some designs we desided that I will weld on a bolt to the ratcher so that we can have a veriable length shaft connected.		Judgement: decision	MEC	4		
Thursday	Thurs			0		
Arrived	08:00		SOC	-1	Reproductive: practical process	SOCIAL
EPS meeting	09:00		GEN	-2	Summary: practical process (GENeric)	PROFPRAC
Seminaar from R and Pon OHS. Was very inforMATive and enjoyed the conection of class interaction.	10:00		GEN	-3	Interpretation: personal significance	PROFPRAC
seminaar Mr Hn cr and ms. Manufacturing methords.	11:00		GEN	-2	Summary: practical process (GENeric)	PROFPRAC
lunch	12:00		SOC	-1	Reproductive: practical process	SOCIAL
showed my welded ratcet to the groep and started testing it	13:00	Summary: practical process - demonstration	MEC	2		
The test showed that the ratcher that we had will not work	14:00	Interpretation: technical problem	MEC	3		
and that we needed on with smaller intervals.		Judgement: decision	MEC	4		
will buzzy looking at difrent ways Ph-- told us of a one way bearing. Will look into this tomorrow	15:00	Judgement: decision	MEC	-4		RES/PEERS
Friday	Fri			0		
Arrived	08:00		SOC	-1	Reproductive: practical process	SOCIAL
Reading the manual of the rv2aj. Thi is to reset the origin postion	09:00	Interpretation: technical problem	LOG	3		
Ment to bmg to find out about one way bearings.	10:00		GEN	-2	Summary: practical process -	
encounter a problem after reading the manual. Wanted to start up the robot bu encounter error message h0050	11:00	Interpretation: technical problem	LOG	3		
went onto the internet and look what error h0050 is, and found out its an external em switch.	12:00		LOG	-4	Judgement: decision	RES/COP
this buggerded me around alott.	13:00		SOC	-3	Interpretation: personal/prac significance	SOCIAL
Went arround to the groups to find out where this external ems is. Tulani told me its on the front pannel			SOC	-4	Judgement: decided to ask peers	RES/PEERS
after tring and pulling out the wires wand traising wires I because	14:00	Summary: practical process -	ELE	2		
I wanted to find out if I can bypass this ems I went to the internet again			LOG	-4	Judgement: decision	RES/COP
and found out the external ems is actualy on the box itself. This was just a jumper in ourcase not making contact	15:00	Interpretation: significance	MEC	3		
insurted it again and volla it work. I can now confurm that the bateries needs replaising because of the worings on the bax	16:00	Judgement: what needs to be done	LOG	4		

now I could start going threw the origin setup set by step		Summary: practical process -	LOG	2		Reduce these 7 V steps to 1 process
did my first setup broblem. All movements is restricted by 90deg.		Reproductive: object-orientated practical process	LOG	1		
I redid all the steps and again it cange and I could not get full rotation.		Interpretation: significance	LOG	3		
deasemble and tack out the bataries again to reset everything		Reproductive: object-orientated practical process	MEC	1		
started from start.		Reproductive: object-orientated practical process	LOG	1		
Sucsess got home posision setup correctly		Interpretation: significance	LOG	3		

Appendix D 4 Student P Time sheet analysis

Student P TS						
Monday	MON			0		HORIZONTAL - TYPE
HSPA Powerpoint slide creation	8	GEN		-2	Summary: practical process (GENeric)	PROFPRAC
HSPA Research for presentation on networking	9	GEN		-2	Summary: practical process (GENeric)	PROFPRAC
HSPA Research for presentation on networking	10	GEN		-2	Summary: practical process (GENeric)	PROFPRAC
HSPA Research for presentation on networking	11	GEN		-2	Summary: practical process (GENeric)	PROFPRAC
Setting up scalance networking adapters in accordance with CJY guidelines	12	SYS	Summary: technical process	2		
Setting up scalance networking adapters in accordance with CJY guidelines	13	SYS	Summary: technical process	2		
Debugging network problems with Scalance ehternet adapters	14	SYS	Interpretation: identifying technical problem	3		
Debugging network problems with Scalance ehternet adapters	15	SYS	Interpretation: identifying technical problem	3		
Researching on Internet for Scalance adapter help	16	SYS		-3	Interpretation: identifying technical problem	RES/COP
Researching on Internet for Scalance adapter help	17	SYS		-3	Interpretation: identifying technical problem	RES/COP
Tuesday	TUES			0		
Setup of steering test rig	8	MEC	Summary: technical process	2		
Setup of steering test rig	9	MEC	Summary: technical process	2		
Connected up PneuMATic connections of steering rig	10	MEC	Summary: technical process	2		
Started to program steering algorythm using anaLOG positioning with variable flow valve	11	LOG	GENeral: statement about broad SYStem approach; my problem here = this is high end abstract knw but recorded procedurally	5		
Programming steering algorythm	12	LOG	All programming could be '4' re judgements constantly made; but recorded as Summary of technical process	2		
Programming steering algorythm	13	LOG	Summary: technical process	2		
Programming steering algorythm	14	LOG	Summary: technical process	2		
Worked on HSPA presentation, collating slides and revising inforMATion	15	GEN		-2	Summary: practical process (GENeric)	PROFPRAC
Worked on HSPA presentation, collating slides and revising inforMATion	16	GEN		-2	Summary: practical process (GENeric)	PROFPRAC
Worked on HSPA presentation, collating slides and revising inforMATion	17	GEN		-2	Summary: practical process (GENeric)	PROFPRAC
Wednesday	WED			0		
Installation of projector screen for presentations	8	GEN		-2	Summary: practical process (GENeric)	PROFPRAC
Installation of projector screen for presentations	9	GEN		-2	Summary: practical process (GENeric)	PROFPRAC
Dial up presentation for Industrial Networking	10	GEN		-2	Summary: practical process (GENeric)	PROFPRAC
Bluetooth presentation for Industrial Networking	11	GEN		-2	Summary: practical process (GENeric)	PROFPRAC

WirELEss and InfraRed presentation for Industrial networking	12	GEN		-2	Summary: practical process (GENeric)	PROFPRAC
Myself and Mr Rust presented on HSPA , RC car presentation for Industrial networking	13	GEN		-2	Summary: practical process (GENeric)	PROFPRAC
Preperation for H&S seminar for EPS, Research on H&S legislation and implementation	14	GEN		-3	Interpretation: Identified problem	RES/COP
Prepared the H&S slide template for powerpoint presentation	15	GEN		-2	Summary: practical process (GENeric)	PROFPRAC
Prepared forMAT of seminar and roles of presenters.	16	GEN		-2	Summary: practical process (GENeric)	PROFPRAC
Thursday	THU			0		
Prepared for H&S seminar by setting up the projector and altering a few slides	8	GEN		-1	Reproductive: practical process	PROFPRAC
AGENda	9	GEN		-1	Reproductive: practical process	PROFPRAC
Helath and Safety seminar - What is H&S and signage	10	GEN		-3	Interpretation: Practical significance (student's own seminar, based on interpretation of rELEvance in industry)	PROFPRAC
Helath and Safety seminar - Fire safety and PPE	11	GEN		-3	Interpretation: Practical significance (student's own seminar, based on interpretation of rELEvance in industry)	PROFPRAC
Manufacturing methods seminar	12	GEN		-2	Summary: practical process (GENeric)	PROFPRAC
In service training discussion	13	GEN		-3	Interpretation: Practical significance	PROFPRAC
Tutoring CAM	14	GEN		-2	Summary: practical process (GENeric)	RES/PEERS
Tutoring CAM	15	GEN		-2	Summary: practical process (GENeric)	RES/PEERS
Tutoring CAM	16	GEN		-2	Summary: practical process (GENeric)	RES/PEERS
Friday	FRI			0		
Produced updated wiring diagram for refrigeration unit for the refrigeration company to test.	8	ELE	Summary: technical process	2		
Produced updated wiring diagram for refrigeration unit for the refrigeration company to test.	9	ELE	Summary: technical process	2		
Continued work on anaLOG control - using PID, with no success	10	LOG	Interpretation: identifying technical problem	3		
Researched PID control using s7-1200 on internet	11	LOG		-4	Judgement: making a decision that affects working process	RES/COP
Retried PID control, No success	12	LOG	Interpretation: identifying technical problem	3		
Researched alternative control methods for smoothing anaLOG position sensor and valve movement	13	LOG		-4	Judgement: making a decision that affects working process	RES/COP
Tried alternative method using range and increacing dead zones and hysterisis	14	LOG	GENeral: statement about broad SYStem approach;	5		
Registered on Festo website	15	GEN		-4	Judgement: making a decision that affects working process	RES/COP
and researched datasheets of possible solutions	16	LOG		-4	Judgement: making a decision that affects working process	RES/COP
Research of datasheets for possible solutions	17	LOG		-4	Judgement: making a decision that affects working process	RES/COP

Appendix D 5 Student R Time sheet analysis

Student R TS						
Monday	MON			Pi/Pe		HORIZONTAL - TYPE
Admin i.e. CJY, emails	7	GEN		-2	Summary: practical process (GENeric)	PROFPRAC
petty cash requisistion for optical diffusion sensor	8	GEN		-1	Reproductive: practical process	PROFPRAC
researching hspa for networking project	9	LOG		-2	Summary: practical process (GENeric)	RES/COP
Tea Break	10	SOC		-1	Reproductive: practical process	SOCIAL
Battery research weight vs power and optical sensor quotation requests	11	ELE	Interpretation: identifying significance eg. Weight vs power	-3		RES/COP
discussing gearing SYStem for Bubble Car	12	MEC	Interpretation: identifying significance	3		RES/PEERS
LUNCHBREAK	13	SOC		-1	Reproductive: practical process	SOCIAL
reading weekly notes from student at HB ---	14	GEN		-2	Summary: practical process (GENeric)	PROFPRAC
preparing for interview questions and completing interview file	15	GEN		-2	Summary: practical process (GENeric)	PROFPRAC
Tuesday	TUE			0		
Getting prices for rachets and chains for the gearing SYStem	8	GEN		-1	Reproductive: practical process	PROFPRAC
discussing wheels to be used as the steering wheels	9	MEC	Interpretation: identifying significance	3		RES/PEERS
doing final touches to the interview file, buying flip file and pen refill	10	GEN		-1	Reproductive: practical process	PROFPRAC
Going home to dress up	11	SOC		-1	Reproductive: practical process	PROFPRAC
checking that all documents are available, rehearsing possible questions	12	GEN		-1	Reproductive: practical process	PROFPRAC
Driving to HB ---s, SummersetWest	13	SOC		-1	Reproductive: practical process	SOCIAL
Interview with HB---	14	GEN		-3	Describes consciousness of nervousness & implications = interpr	PROFPRAC
Driving home	15	SOC		-1	Reproductive: practical process	SOCIAL
Wednesday	WED			0		
delivery of festo components	8	GEN		-2	Summary: practical process (GENeric)	PROFPRAC
taking inventory of delivered goods	9	GEN		-1	Reproductive: practical process	PROFPRAC
helping L--- with edgecam & starting to write down dimensions of required framework	10	MAT	Interpretation: identifying significance	3		RES/PEERS
measuring alu profile and cutting into pieces	11	MAT	Reproductive: object-orientated practical process	1		
assembling alu profiles to meet the constrains from the prototype design	12	MEC	Summary: technical process	2		
LUNCHBREAK	13	SOC		-1	Reproductive: practical process	SOCIAL
wheel research, i.e. alternative lighter, less rolling resistance	14	PHY	Judgement: making a decision that affects working process - they 'need' less rolling resistence	-4	Suggests decision re need	
helping lambrechst to cut aluminium 40mm rod & admin	16	MEC	Reproductive: object-orientated practical process	1		RES/PEERS
Thursday	THU			0		

assemblying festo connectors to tank	8	LOG	Summary: technical process	2		
meeting start	9	GEN		-1	Reproductive: practical process	PROFPRAC
seminar discussion i.e. contents of seminar and dates	10	GEN		-3		PROFPRAC
quick coffee break, application status for companies	11	GEN		-1	Reproductive: practical process	PROFPRAC
application status for companies	12	GEN		-2	Summary: practical process (GENeric)	PROFPRAC
LUNCHBREAK	13	SOC		-1	Reproductive: practical process	SOCIAL
Connecting optical diffusion sensors and calbrating them to see how well they work	14	LOG	Interpretation: identifying potential technical problem	3		
hooking up festo pneumatic connectors to the prescribed method	15	LOG	Summary: technical process	2		
Friday	FRI			0		
setting up new laptop i.e. installing programs for Tech and transferring data from old to new	8	GEN		-2	Summary: practical process (GENeric)	PROFPRAC
installing Microsoft office and Solidworks on separate Laptop	9	GEN		-2	Summary: practical process (GENeric)	PROFPRAC
designing the framework to decide where the wheels, drive and sensor go	10	SYS	Judgement: making a decision that affects working process -	4		
designing the framework to decide where the wheels, drive and sensor go	11	SYS	Judgement: making a decision that affects working process -	4		
programming HMI to test anaLOG interface of the bubbles car	12	LOG	Judgement: making a decision that affects working process -	4		
LUNCHBREAK	13	SOC		-1	Reproductive: practical process	SOCIAL
Industry visit to A---, showing workshop and the different machines	14	GEN		-2	Summary: practical process (GENeric)	PROFPRAC
Industry Visit to A---, explaining the companies Hierarchy and answering other questions	15	GEN		-2	Summary: practical process (GENeric)	PROFPRAC

Appendix E1 Interview 1 transcript

Question	Transcription	Turn	Know	Sp	Pi/Pe	Coding
Interview 1. What is this?	L: These are the fluid muscles which are connected over there.	1	MEC	L	1	object description
	We need to build a bracket so that they can't pull out and can get the power stroke in. Then ... Gearing system on the side, and jockey on here to tension it,	2	MEC	L	3	Interpretation - why elements are needed
	so as to change between two gears.	3	MEC	L	4	decision about action, based on technical req.
	Basically, we don't know how good it's going to work, that's why we are building a rig to test it. Then I'm going to hand it over to J to test a Cam system	4	MEC	L	4	Explain decision
So you are running many diff kinds of tests?	[DEMO 1-way bearing]	5	MEC	P	1	Object demonstration
Isn't this a waste of motion/energy?	P: It's actually very efficient. If you look at these muscles here.	6	MEC	P	4	Judgement
	There is actually a spacer that goes on the back and there's a nut that locks into the spacer, so essentially [unscrews nut to maximum] it looks something like that... That'll be a smaller version, it's a lot more exaggerated	7	MEC	P	1	Object demonstration
	So that there is space for this to expand backwards, instead of the muscle contracting...	8	PHY	P	4	Drawing conclusion/theoretical
	Because of the space, the second it comes past the maximum extension, it's losing energy to the expansion it then has here [points to opposite end]	9	PHY	P	5	General principle
	as well as the fact that at that point you then have minimum torque because of the position of the shaft in relation to the central pivot point,	10	PHY	P	5	General principle
	which means it is actually incredibly inefficient. (?? CONTRADICTION?)	11	PHY	P	4	Judgement
Why are you testing it then?	Mr H wants to see it working;	12	GEN	P	-3	interpretation/significance generic: Must test all possibilities
	R: Also we have to have a back-up.... [All talking, P picks up shaft with one way bearing]	13	GEN	R	-3	Interpretation based on experience: NB of 'plan B'
Whose idea to use this? [Shaft and bearing]	Mr T's idea. L: Killing people, hunting with a bow, a compound bow.	14	SOC	L	-3	Interpretation/ metaphor
	T: The compound bow uses a cam System for extending the distance of your pull. That works on a variable System for different kinds of (poundages??)	15	SOC	T	-5	Experiential/principle - this is how a similar system works (system metaphor from social/exp world)
	So I was thinking maybe something like that,	16	SOC	T	-4	Judgement; decision to try sth based on experience
	because the distance with the fluid muscle only gives you 2cm, but with a cam SYStem you can increase that and increase the movement.	17	MEC	T	5	General principle
What made you think of that?	L: It's Mr T's love of the outdoors!	18	SOC	L	-3	Interpretation of significance of observation
	T: We only now realise that there is a thing like one way bearings and not many people sell them,	19	GEN	T	-4	broader engineering/prof prac eg. Costing, sourcing, supply; implies R made decision to find one
	but luckily with Mr R's genius at finding things on the internet, we managed to find one	20	SOC	T	-3	Interpretation/ significance of Mr R's ability = enabled them to find one
What made you think of a one-way bearing?	T:...P: We were going with a bicycle system [picks up gear to demonstrate]	21	MEC	P	1	Object process
	we figured a bicycle goes click-click as it goes round, but if you pull the other way it then	22	MEC	P	3	Interpretation/ significance

	locks in.					
	The problem with that was the second we built a test rig we realised these muscles don't even contract enough to go one click. We had to find a more accurate SYStem.	23	MEC	P	4	decision about action, based on technical req.
	P: Also because of the ratchet & pull system a bicycle uses, it has a little bit of play before it locks in,	24	MEC	P	2	Object function/ summary
	so that would be lost energy. Whereas [picks up shaft with one-way bearing] here there is no play whatsoever.	25	PHY	P	3	interpretation/significance
	P: I think it was T's idea... T: I thought of using a bicycle, ... But my idea incorporates P's (including ratchet)	26	SOC	T	-3	Interpretation/significance
Who made you think of a bicycle?	T: WE have to use the muscle	27	MEC	T	1	industry/academic text criteria
	P: When we saw this (muscles) on the prototype the first thing we noticed was 1stly it's a 4-wheel car but [demonstrates] it's a one-wheel drive.	28	MEC	P	1	experiential - observation
	Now their car never reached top speed because basically there wasn't enough torque...	29	PHY	P	4	Judgement
	Because this has quite a high rotation but not enough torque, so you lose a lot of energy because of the way the system works.	30	PHY	P	5	General principle - without torque a car would not reach top speed

Appendix E 2 Interview 2 transcript

Question	Transcription	Turn	Know	Sp	Pi/ Pe	Coding
Interview 2. Explain to me why you did this.	The system is designed like this because they require line-following. There is a figure of 8 on the track and a straight line for the drag race. They supplied 2 sensors and a double-acting cylinder for the steering which has to be done by pneumatics and they also supplied a position sensor which goes on the actual cylinder.	32	SYS	P	1	industry/academic text criteria
	But after testing it we saw that the senosr doesn't sense the entire length of the stroke. It only senses about 27mm of the 40mm length it has to travel on the cylinder.	33	MEC	P	3	Interpretation/ significance
	So we have engineered a system	34	SYS	P	4	decision about action, based on technical req.
	whereby a potentiometre turning on a rack and pinion system does the positioning of the cylinder.	35	MEC	P	5	General principle
	What this means in practical application is that 1stly this (cylinder) gives a position to the PLC which then has a reference point given by this potentiometre.	36	LOG	P	2	Summary
	By changing the position of the pot you can change the position of the cylinder. The purpose of this is that it has to know its postion.	37	MEC	P	5	General principle
	If I move it out the way (demonstrates) it returns to its position.	38	MEC	P	1	Object function
Would everyone be using this?	No, the system they've supplied is basically the 2 sensors and the position sensor on the cylinder. [demonstrates]	39	MEC	P	1	industry/academic text criteria
	R: We wanted more precision using many sensors...	40	PHY	R	4	Judgement/decision
	P: So it gives a magnitude, instead of just saying turn wheel.	41	PHY	P	3	interpretation/significance
	This is the original sensor they supplied. It's an analogue sensor, but it doesn't have the travel we require.	42	PHY	P	4	industry/academic text criteria/ judge
	[demonstrates] I figured this out when I tried to make it turn the full way and it wouldn';t. It was actually B who suggested a row of lights [S** trainer]	43	SYS	P	3	Interpretation/significance
	However, our major breakthrough came when I realised that PLC does PWM...	44	LOG	P	4	Drawing conclusion/theoretical
	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.	45	PHY	P	5	Underlying technical concept
	That's what you can hear with the 'buzzing' - it's actually the solenoids turning on and off very quickly.	46	ELE	P	3	explanation of significance
	A perfect example is the line following. I didn't do any calculations. I thought ok, we need to position the cyclinder, what are our options? I went procedurally through let's try an analogue positioning valve, we tested that and it didn't work.	47	LOG	P	2	Summary (meta-awareness, experiential?)
	But from that I realised	48	MAT		3	Interpretation of significance
	that the mathematical formulas to get accurate positioning would be such, such and such.	49	MAT	P	6	Abstraction: NOTE KEW had seen calculations/ PWM simulation
	And then developed very simple principles into quite complicated mathematical algorithms.	50	MAT	P	4	Judgement/decision
I don't see where algorithms come in at all?	Ahh, but none of the values coming in are relative to anything else. Essentially it's signal conditioning, then signal processing, then signal outputs.	51	LOG	P	5	GENeral principle
	The first 2 go through about 10 different processes becfore it comes to an actual output.	52	LOG	P	2	Summary of function
	My first code was quite convoluted. I, going back now, couldn't even understand it, but because I then understood how the systems worked, I then went and redesigned the code and streamlined it, and realised what parts I can leave out	53	LOG	P	4	decision about action, based on technical req.
How did you know to do that - PWM?	Through a development board called the Arduino, I have used it before.	54	LOG	P	3	Interpretation based on experiential - own.
	They call it analogue out and you just write in a value between 0 and 255,	55	LOG	P	1	Object' value
	but after having googled a large amount on PWM for that I have a much better understanding.	56	SYS	P	-4	Decision to read up on PWM

Appendix E 3 Interview 3 transcript

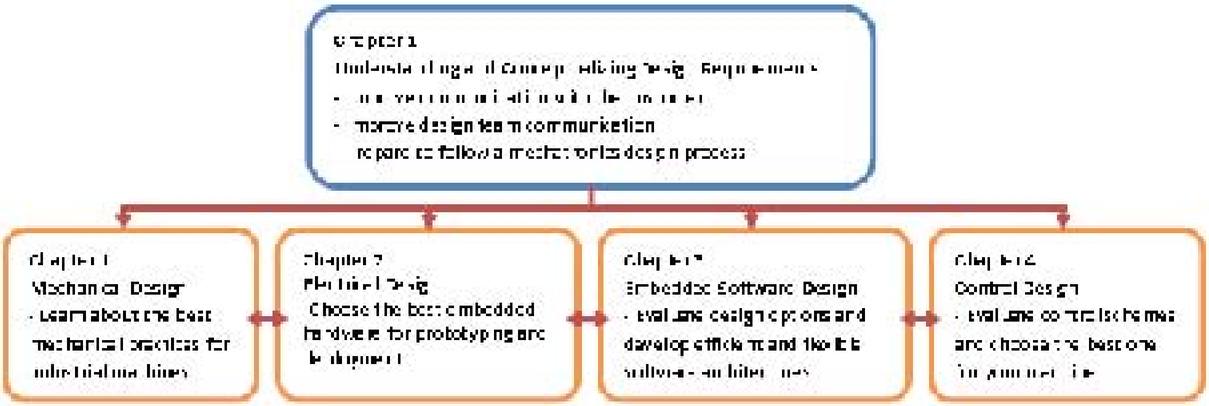
Question	Transcription	Turn	Know	Sp	Pi/ Pe	Coding
Interview 3.	Basically what the problem is is when the car moves in the figure of 8 we need to differentiate between the pitlane, that's crossing the figure 8 and the crossing of the figure itself. So the car needs to decide should it go left or right	66	SYS	R	3	Interpretation of problem
	So what I was thinking for the program was to work out the movement of the car	67	LOG	R	4	Decision
	and from there we can set a counter and see when it picks up two lines	68	LOG	R	3	Interpretation of significance of action
	For each count it has a certain condition. If it's condition 1, it's go left, count 2 go right and so forth	69	LOG	R	1	Object process
	we need to change those counts though because we don't know how many lanes/ uhh tracks [means 'laps'] it can go	70	MAT	R	4	Decision
	It depends on how many times it can go round	71	SYS	R	3	Interpretation
Until it needs to stop in the pitlane to refuel?	Yes, because then the conditions change, because you're going the other way on the figure of 8	72	LOG	R	3	Interpretation
And you're only allowed to do this once?	It is only possible to do it once [pitstop], because as soon as you turn around, you can't enter the pitstop any more because the lane is only on one side	73	MAT	R	5	Underlying principle (geometric)
In terms of the competition itself, what does that mean? Do you know how long you can run for?	The points we get are for speed and distance travelled, so basically we should go round the track as far as possible, because the weighting for distance outweighs speed,	74	SYS	R	4	decision
	so endurance is better	75	GEN	R	5	General principle
So, the air is about potential speed	The pressure is set, but the rate at which the fluid muscles fire...	76	PHY	R	2	Summary
	We have a nice ratio worked out which balances speed versus efficiency	77	MAT		3	Interpretation
I saw that... The way the muscles are working... What does PWM have to do with that?	The PWM is only for the steering of the wheels, basically the wheels are...the pneu cyl which steers the wheels is triggered with PWM.	78	SYS	R	5	General principle
	It enables us to proportionally control	79	MAT		4	Judgement (decided they needed to proportionally control...)
	the position of the wheels according to the sensor...	80	PHY		2	Summary
	PWM enables us to control it more accurately rather than... fully pressurising the cylinder	81	LOG	R	5	General principle
Issue with line following... How difficult is this going to be? Practically?	The difficulty is getting behind it [German concept] and figuring it out in theory before you go to program it	82	SYS	R	-5	General principle re working process
	and when you program it you need to concentrate very well in order not to lose sight of what has been done and what needs to be done.	83	SYS	R	-5	General principle re working process

Appendix E 4 Interview 4 transcript

Question	**Transcription**	**Turn**	**Know**	**Sp**	**Pi/ Pe**	**Coding**
Interview 4. What's the problem?	Mz: let me demonstrate. You have the gripper holding the cylinder in this poosition, now the robot has to move around and sense the hole.	1	MEC	M	1	object process
	Now if you notice my hand holding it in this position.	2	MEC	M	-1	object process (metaphor)
	Now my hand has different axis. Each axis has diff points [indicates wrist, elbow, shoulder]	3	SYS	M	-3	Interpretation/ metaphor of system using human body
	It can't move straight to this side because each axis has reached a limit	4	MEC	M	5	General principle - the way multiple axes work?
demo	it has to move here, then undo that limit otherwise it can't move further.	5	LOG	M	4	Judgement : 'It has to...' ('undo limit = logic, ie programming)
	The way the gripper is designed you have to put it [cyl] down before you can hold it with this [diff] part.	6	MEC	M	1	Object procedural description
	You have to let go the outer part, but hold the inner part. The inner part can be held like with a palm [demonstrates palm gripping inner part and rotating].	7	MEC	M	1	Object procedural description
How did you solve the problem?	You need to put it down and let it go over the light sensor. Once it senses a part it goes on, but when not it stays off.	8	ELE	M	1	Object procedural description
So you placed it, let go, the gripper realigned itself	Yes and then moved it around, then moved it around again. But you have to move it at a degree	9	MEC	M	4	Judgement/Decision (based on my statement 'so you...')
	You need to keep in mind 1. you don't want your robot to reach its limits,	10	MEC	M	5	General principle -axes limits

Appendix F NI Mechatronics machine design guide extract

With this guide, learn step-by-step best practices for the machine design process, starting from understanding customer requirements and conceptualizing design ideas in chapter 1 to following the mechatronics-integrated design approach, lowering design risk, and increasing machine productivity in chapters 2 through 4. Throughout the guide, in-depth application examples illustrate the approaches successful designers implement. Finally, use the [illegible] tutorials referenced in the chapters to take the next step and incorporate the recommended best practices. Following is an overview of the machine design process covered in this design guide.



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