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Vocational pedagogy in Automotive Mechanics: Ontological dimensions and Cognitive Load Theory implications

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ABSTRACT

This research explored the way ontological categories are fundamentally useful for analysing vocational pedagogy, particularly in the context of Automotive Mechanics. Two ontological traditions were found to be especially useful: mereology, with its focus on part–whole systems, and process ontology, which emphasises the dynamics of change. The convergence of ontological categories with learning science in Automotive Mechanics pedagogy is also examined, particularly the way in which cognitive load theory helps to manage the learning complexities tied to ontological automotive concepts. The research, which targeted first-year student training, employed a qualitative case study methodology encompassing three vocational education and training institutions in Eswatini that provide training in Automotive Mechanics. The data collection involved conducting interviews with lecturers, making observations in both classrooms and workshops, and recording the teaching process on video during a one-year period. Field notes and transcriptions were analysed in order to extract key themes connected to the teaching methods. These themes were identified, grouped and further condensed to isolate the most prevalent teaching practices across the institutions. Upon identifying a significant theme pertaining to parts and wholes, the researchers delved into the philosophical and theoretical aspects of part–whole relations and their role in teaching and learning processes. They discovered beneficial interconnections between mereology, process ontology, and cognitive load theory, especially the way the hierarchical structure of Automotive Mechanics pedagogy interacts with the constraints of working memory and chunking. These connections both foster in-depth pedagogic analysis and contribute to the enhancement of Automotive Mechanics pedagogy.

KEYWORDS

Automotive Mechanics pedagogy; ontology; mereology; process ontology; cognitive load theory

Introduction

Teaching and learning in vocational fields such as Automotive Mechanics necessitates understanding the many intricate, interconnected components and systems and the dynamic processes they undergo. This places cognitive load demands on students negotiating the multiplicity of parts and systems in cars. We can phrase the above challenge as a problem statement: How can detailed analytical concepts derived from ontology intersect with recent developments in learning science and be related to Automotive Mechanics pedagogy? In this context, we explore the potential synergies of mereology, process ontology and cognitive load theory in the pedagogy of Automotive Mechanics.

Mereology – the abstract study of parts and the wholes they form (Cotnoir & Varzi, 2021) – can provide a specialised analytical language that helps to delineate key aspects of Automotive Mechanics pedagogy. It serves as an abstract analytical counterpart for the dissection of complex mechanical systems into manageable parts and facilitates a progressive understanding that starts with individual components and incrementally ascends to comprehending an entire vehicle's system. Given the intricate nature of Automotive Mechanics, such a 'parts to parts to system' methodology can prove to be a useful analytical pedagogical tool. It offers an already established and well-developed systematic language of description that aids an understanding of the complex hierarchy of parts, systems and subsystems that make up a vehicle.

Process ontology, a philosophical perspective that emphasises the dynamic nature of reality (Whitehead, 1929), focuses on processes and transformations. Instead of viewing a motor car as, for instance, a static assembly of parts, process ontology encourages us to view it as a complex network of interacting processes that evolve over time. This dynamic perspective is particularly relevant in the automotive field, where systems constantly interact, parts wear down, and mechanical elements fluctuate over time.

Cognitive load theory (CLT) provides insights into the cognitive demands placed on students and proposes strategies to manage these demands so as to enable effective learning (Sweller, Ayres & Kalyuga, 2011). In the context of Automotive Mechanics, the complexity of concepts and the multitude of interrelated parts and systems can exert a high cognitive load on students. CLT-based strategies – such as breaking down a specific task (intrinsic load), reducing unnecessary distractions (extraneous load), and facilitating meaning-making (germane load) – can help to make the learning process more efficient. By managing cognitive load, students can more easily engage in higher-level cognitive processes such as problem-solving and meaning-making without experiencing cognitive overload.

The structure of this article unfolds by first establishing the conceptual framework designed to analyse the pedagogy of Automotive Mechanics. This is presented as three triads:

- Mereology comprises three subconcepts: part of, overlap, and transitivity of parthood;

- Process ontology includes three subconcepts of its own: process, change, and temporality; and
- Cognitive load theory encompasses three core concepts: intrinsic cognitive load, extraneous cognitive load, and germane cognitive load.

Secondly, a brief account is provided of the case study methodology employed, along with the research sites (three TVET colleges in Eswatini) and participants (six highly experienced lecturers), the data having been gathered during a one-year period.

The third section of this article includes a discussion of the study findings using both detailed lesson transcripts and lecturer interviews to illustrate the applicability of mereology, process ontology and cognitive load theory to the analysis of Automotive Mechanics pedagogy. The article concludes by arguing that the framework developed possesses not only analytical utility, but also pedagogic effectiveness, thus providing a 'double bonus' for subject-specific vocational pedagogy.

Conceptual framework for analysing Automotive Mechanics pedagogy

Why use mereology as part of a conceptual framework for Automotive Mechanics pedagogy?

Mereology is not well known as a useful tool in vocational pedagogy. This is understandable, given that its roots lie in mathematical set theory, logic and ontological philosophy.[1] The term originates in the ancient Greek word 'meros', which means 'part' and the wholes built up from parts. Mereology focuses on the ways in which parts relate to parts and how systems are built up and then form parts of larger systems (Cotnoir & Varzi, 2021:1). Put like this, the connection to Automotive Mechanics becomes obvious, given the way engines are made up of subsystems and parts that interrelate. Mereology enables us to use a well-established analytical language with a long historical record going back to Plato and Aristotle and carrying forward to modern figures such as Whitehead. Many of the complexities, contradictions and nuances of the way parts and wholes work have been thrashed out over the ages, with increasing clarity reached on what the basic concepts and processes are in this area. This has enabled us, as researchers in and of education, not just to rely on emergent themes from the data, but to put to use a massive amount of established intellectual work already done in the field. We would argue that there is real virtue in this strategy of respecting the weight of intellectual history rather than using the latest fashionable framework that tends to die with its founder. We shall use only three fundamental concepts from the massive corpus of mereology to reveal its possibilities for Automotive Mechanics pedagogy: they are 'part of', 'overlap' and 'transitivity of parthood'. These are explained in what follows.

1 See Varzi (2019) for a clear introduction and a description in the *Stanford encyclopedia of philosophy*. See, also, Cotnoir and Varzi (2021) for the clearest, fullest and most up-to-date account.

'Part of': This is the most fundamental concept in mereology. It refers to the relation between a part and the whole.

> Parthood is the fundamental relation in Mereology, and it is usually defined as the relation that holds between a whole and its proper parts (Cotnoir & Varzi, 2021:1).

For instance, in Automotive Mechanics, a piston can be considered to be a part of an engine and the engine itself is a part of the car. The 'part of' relationship establishes a hierarchical system where the function of each part is contextualised in the broader system to which it contributes.

'Overlap': This refers to a situation where two or more parts share a common part across different systems (Cotnoir & Varzi, 2021:47). Overlap becomes relevant in Automotive Mechanics when components serve multiple systems. For example, a car's battery overlaps with multiple systems: it provides the spark for starting the engine, powers the electrical systems when the engine is off, and contributes to the charging system when the engine is running.

'Transitivity of parthood': This is the principle that if part A is a part of part B and part B is a part of whole C, then part A is also a part of whole C (Cotnoir & Varzi, 2021:76). In the context of an automobile, if we consider the spark plug (part A) as a part of the ignition system (part B) and the ignition system as a part of the overall car (whole C), then the spark plug is also a part of the whole car. This concept helps us to understand how small, individual parts contribute to the overall functioning of an automobile, even though they are nested within larger subsystems. Transitivity is vital to diagnostics and problem-solving in Automotive Mechanics. It also plays a key role in understanding how chunking works in cognitive load theory (to be discussed below).

Teaching Automotive Mechanics is replete with parts within parts and the systems they form and interrelate with. It is almost too obvious to state, but stating it and providing the analytical subconcepts enables us to name and track an intuitive teaching process explicitly.

When discussing a cooling system, for instance, a lecturer might start by identifying the radiator, the water pump and the coolant (the parts) that collectively make up this system (the whole). The overlap of these parts with other systems, such as the water pump driven by the engine's drive belt, can be highlighted to illustrate their multiple roles. Then, using the principle of transitivity of parthood, the students can be guided to see how each part contributes to the cooling system and the function of the car as a whole. We are not arguing that the lecturers should say in the lessons that they are using transitivity of parthood, but rather that we have and use a rigorous analytical language to support a theoretical interrogation of Automotive Mechanics pedagogy.

Process ontology in the context of Automotive Mechanics with specific attention to its core concepts: Process, change and temporality

Alfred North Whitehead was a key figure in developing mereology in the 20th century. He also sits as a foundational philosophical presence in education, especially through his collection of essays, *The aims of education and other essays*, in which he offered a synthesis of liberal, scientific and vocational education (Whitehead, 1929a:74–75). Whitehead's philosophy of education was deeply informed by process ontology (Whitehead, 1929b), which took mereology and 'made it dance' (author's own choice of words). There are real dangers when dealing with parts and parts in combination that the approach becomes static: parts go together with parts to make up a whole, nicely drawn up and labelled in static diagrams, whereas, actually, it is how they work and what they do that are vital. Process ontology helps us ward off the static, immobile dangers of working with parts and focuses on their actions. As with mereology, we use three fundamental concepts to illustrate this: process, change and temporality.

'Process': As the key concept in process ontology, a process represents a series of actions or operations pushing towards the future. In the Western intellectual tradition, this idea goes back to Heraclitus and his dictum:

> No man ever steps in the same river twice, for it's not the same river, and he's not the same man (Kahn, 1979:91).

As a philosophical concept, process pushes against the tendency to work with things, substances or products in a reified way. Instead, it places them into the stream (or fire) of dynamic transformations (Rescher, 2000:5). In the context of Automotive Mechanics, a process could refer to the steps involved in the combustion cycle in an engine. This includes the intake, compression, combustion and exhaust processes. Rather than simply teaching students about the static components of an engine, a process ontological approach would emphasise the dynamic activities that these parts engage in to power the vehicle, with the focus shifting away from the parts that make up the system to the energetic flows of the system pushing it forward.

'Change': Change is inherent to the process concept and signifies the transition or transformation in a system (Rescher, 2000:22). Change is integral to understanding the operation of a motor vehicle and diagnosing problems in Automotive Mechanics – for instance, understanding how the wear and tear on brake pads can change braking efficiency or how a change in the colour of exhaust smoke can indicate different engine (mal)functions or problems. This focus on change helps students grasp the dynamic nature of automotive systems.

'Temporality': Temporality builds on process and change and pushes towards the realisation that things do not just exist in time; rather, temporality is built into the way the world works. The reality of the world is not static; it is constantly dynamic, changing, temporal and shifting between states. Whitehead puts it this way: 'The actual world is a process, and temporality is the form of process' (Whitehead, 1929b:236). When teaching Automotive Mechanics, temporality mainly refers to the way the students should come to see the car as always in time, with everything the car does related to movement in time and the inevitable decay that comes with time, as well as the continual innovation and fecundity possible because of these dynamics. This insight goes from the smallest combustion sequence to the timing of different processes, like the precise sequence and timing in a four-stroke combustion cycle, building towards longer-term processes such as the lifespan of certain parts or the maintenance schedule for different systems in the motor car.

Using a process ontological lens in Automotive Mechanics pedagogy gives individuals a holistic, dynamic perspective. As a result, instead of seeing a motor car as merely a collection of parts, to individuals the automobile becomes a network of constantly interacting, changing, evolving and decaying processes over time. Understanding these processes can significantly enhance the students' diagnostic and problem-solving skills, preparing them for real-world challenges in Automotive Mechanics.

How does cognitive load theory relate to mereology and process ontology?

Cognitive load theory (CLT), developed by John Sweller and various compatriots (Sweller, Ayres & Kalyuga, 2011), posits that our working memory is limited. The design of learning tasks should put this limitation of working memory foremost when considering ways to optimise learning outcomes.

Cognitive load is divided into intrinsic, extraneous and germane loads.

'Intrinsic cognitive load': This refers to the inherent complexity of the information or task being learned, which is determined by the number of interactive elements that must be processed simultaneously in working memory. Sweller puts it succinctly:

> Intrinsic Cognitive Load is the amount of mental effort required to process a given amount of information (Sweller, 1999:13).

In the context of Automotive Mechanics, understanding the principles of internal combustion would impose a high intrinsic load because of the various elements involved: fuel–air mixture, compression, spark ignition and exhaust. All these elements must be understood in conjunction with one another, as they interact in a complex process. As a technical aside, intrinsic load depends on a student's prior knowledge of an area being studied, so, if the student already has a strong overall grasp of how the mechanics of a car works, this will reduce the intrinsic load on the student. The more expert the student is in the area being taught, the less the inherent complexity of a task will be compared with that of a novice student.

'Extraneous cognitive load': This refers to the load imposed by how information is presented to students. There will always be some kind of extrinsic load when teaching, as the information needs to be presented in some pedagogic form. When instructions are poorly designed, are unclear or are unnecessarily complex, the extrinsic load becomes extraneous (excessively high or unimportant to the actual learning process), thereby hampering learning.

> Extraneous Cognitive Load is any Cognitive Load that is not essential for learning and that can therefore interfere with learning (Sweller, 1999:18).

For instance, if an instructor explains the internal combustion process in a long-winded way, or students must refer to multiple resources simultaneously to understand a task, this could create a high extraneous load.

'Germane cognitive load': This involves the mental effort required to construct and automate schemas, which are the mental structures we use to organise and store knowledge. Sweller (1999) puts it clearly:

> Germane Load is the cognitive processing that is essential for meaningful learning to occur (Sweller, 1999:17).

High germane load is desirable because it contributes to meaningful learning. For example, after understanding a car's various parts (a task with a high intrinsic load), a student might start to see how these parts interrelate to make possible the car's functioning. This insight would involve a high germane load, as the student is required to integrate multiple elements into a coherent schema. Schema construction is central to the pedagogy of Automotive Mechanics, enabling problem-solving that is driven by material inferences.

In an effective learning environment, the goal is to manage these three types of cognitive load in order to optimise learning within the limitations of working memory. Optimisation often involves minimising extraneous load (e.g. by providing clear instructions and well-organised learning materials), managing intrinsic load (e.g. by breaking down complex tasks into manageable parts), and maximising germane load (e.g. by encouraging students to make connections between concepts and practice while they are building schemas).

In the pedagogy of Automotive Mechanics, focusing on intrinsic load might involve breaking down a motor car's operation into its parts and systems so that students can focus on understanding one element at a time. Efforts to reduce extraneous load could involve laying out engine parts that can easily be fitted together. Finally, strategies to increase germane load could entail guiding students to connect the parts and systems they are learning about and encouraging them to apply this knowledge in real-world problem-solving tasks such as diagnosing and resolving mechanical issues.

Integration of mereology, process ontology and cognitive load theory to enhance Automotive Mechanics pedagogy

There are real synergies, for both pedagogic analysis and effective teaching, in the ways mereology, process ontology and cognitive load theory work together. Before going on to demonstrate this in the discussion of the findings, we would like to make this explicit, not as formal integration but as intuitive synergies between them.

Mereology has the danger of becoming static in the breaking up of systems into subsystems and parts. When breaking up things into pieces, it is hard to remember that they are also processes in dynamic change. On the other hand, when working with process flows, it can be difficult to return to the elements making up the flow. This is a continuous productive tension in theorising: the structure of the parts in a system versus the actions the system takes for an outcome; a state of things at a certain point versus a change from one state to another; the static pattern on repeat versus flux in movement; the structure of a system versus the function of a system; and so on. By clearly working with both mereology and process ontology, both ways of working with the real world are present.

Cognitive load theory fundamentally recognises that working memory is limited and that chunking is a key strategy with which to continuously increase the intrinsic complexity of a subject by combining many parts into one whole, and then only having to work with the one whole and not the many parts, thus reducing cognitive load. The more proficient designers of learning are at working with systems within systems within systems, the more they are able to pack increasingly higher levels of complexity into the teaching and learning process while not overloading working memory.

Finally, germane load is all about meaning-making and schema production, where interrelationships and connections to existing knowledge are made. This is exactly how components interact with subsystems and subsequent higher-level systems through recognising patterns and making connections. But, even more importantly, these dynamic connections work with each other, overlapping and intersecting, making it crucial that students make synthetic sense of the ways in which cars function. All of this sense-making and schema-production are ultimately brought to bear in order to meet the key demand that automotive mechanics be able to diagnose and fix a problem with a vehicle.

Methodology

This study is anchored in a multiple case study approach, which formed part of a larger PhD research study (Mokoena, 2017). The objective was to investigate the pedagogical practices employed in teaching Automotive Mechanics across three vocational education institutions in Eswatini. Data for this research were collected primarily through semi-structured interviews with lecturers who specialised in training students in Automotive Mechanics, and also from observations made in classroom and workshop settings over one year.

A case study methodology was used to examine complex phenomena comprehensively within their real-life context (Yin, 2003). While a single case study could have offered a deeper observational understanding of the subject under scrutiny, we chose a multiple case study across institutions to improve the external validity and dimensionality and to enable the development of more comprehensive theories (Yin, 2003; Barratt, Choi & Li, 2011).

For this study, the participants were selected by means of a purposive sampling approach. This non-probabilistic sampling technique was considered suitable bearing in mind the specialised scope of the study. From each institution, two lecturers were selected based on their length of service – one with the longest service record and another with a minimum of ten years' service. This method ensured the inclusion of a wide spectrum of experiences and viewpoints.

To ensure confidentiality, the participants are represented by their respective institutions and a numerical identifier, as shown in Table 1.

Table 1: Research participant lecturers and their lecturing experience

PARTICIPANT	INSTITUTION	LENGTH OF EXPERIENCE	QUALIFYING CRITERION
ECOT1	Eswatini College of Technology	24 years	Ten-year service period
ECOT2	Eswatini College of Technology	29 years	Longest service period
VOCTIM1	Gwamile VOCTIM	29 years	Longest service period
VOCTIM2	Gwamile VOCTIM	10 years	Ten-year service period
MITC1	Manzini Industrial Training Centre	18 years	Ten-year service period
MITC2	Manzini Industrial Training Centre	22 years	Longest service period

The data-collection methodologies for this study encompassed pre- and post-observation semi-structured interviews with each participant, direct observations of pedagogical practices in classrooms and workshops, and video footage. This multifaceted approach allowed for a deeper examination of teaching practices and facilitated the real-time capture of data on teaching strategies and student–lecturer interactions. All the interviews and observations were limited to first-year training in order to offer a clear reference point for the pedagogical strategies employed at the foundational level of Automotive Mechanics instruction.

The intention was to interview all automotive lecturers at these institutions, but practical constraints and timetable clashes allowed only two lecturers per institution to be included in the study. The distribution of the selected lecturers is represented in the Table 2.

Table 2: Sampling of lecturers by institution

INSTITUTION	TOTAL NUMBER OF LECTURERS IN AUTOMOTIVE MECHANICS	NUMBER OF LECTURERS SELECTED FOR DATA COLLECTION
Eswatini College of Technology	4	2
Gwamile VOCTIM	4	2
Manzini Industrial Training Centre	2	2

In practical terms, only four lecturers were excluded from the study, specifically two each from Eswatini College of Technology (ECOT) and VOCTIM.

The researcher (Mokoena) sought to maintain a low profile so as not to disturb the natural teaching environment. To this end, he adopted the student dress code of blue two-piece overalls for all the lessons, further enhancing the researcher's inconspicuousness. This approach was beneficial in enabling students and lecturers to behave naturally without experiencing the stress of an outsider's presence, especially as the study extended over a year.

Data sourced from interviews, observations, field notes, and transcriptions were coded by grouping related ideas reflecting broader perspectives (Creswell & Plano Clark, 2011). An intensive process of reading, noting key phrases, assigning codes, grouping themes, and identifying common themes across all three institutions was followed. These themes were analysed for their contribution to lecturer pedagogy in Automotive Mechanics.

When the key theme of part/wholes emerged, the researchers investigated which detailed theoretical languages would best help to analyse the data. The gambit was that already well-developed theories on part/whole relations could provide specific and semantically dense conceptual tools to help with the analysis. This was how mereology and process ontology became key analytical tools in the study.

Potential bias introduced due to the selection of participants was limited by the relatively small number of automotive lecturers in each institution. This study's findings, though based on evidence from one developing country in Africa, offer a premise that the theoretical frameworks underpinning the pedagogical practices in Automotive Mechanics teaching could apply to other areas of engineering and to many vocationally oriented subjects with real-world roots.

Discussion of findings: The 'parts-parts-system' pedagogy in relation to mereology and process ontology

What follows is an exemplification, through the data collected, of the way the ontological categories of mereology and process ontology show up in the pedagogic processes of Automotive Mechanics. We begin with a short extract from a practical assessment lesson by the Ministry of Information Technology, Communication and Innovation (MITCI) (16 September 2015) on removing and replacing brake pads.

For those who are not mechanics, a little context is needed on the difference between the two types of braking systems in most cars – disc brakes and drum brakes. When you pull up your handbrake, you use drum brakes; when using a foot pedal, you normally use disc brakes. One of the main parts of a drum brake is a brake shoe, while a main part of a disc brake is a brake pad. In this specific instance, the students are working with brake pads as a part of the disc brake system but will also need to know how brake shoes work in the drum-braking system.

Brake shoes and brake pads lesson extract

Lecturer: Give me one advantage and one disadvantage of brake shoes as opposed to brake pads.

Trainee: [No response] The lecturer notes something down.

Lecturer: [Points] What are these?

Trainee: Studs.

Lecturer: What is this?

Trainee: Brake piston.

Lecturer: … and this?

Trainee: Disc.

Lecturer: What is this?

Trainee: Mmm … it carries the brake fluid … .

Lecturer: What is it called?

Trainee: [No response]

Lecturer: It is called a brake fluid flexible pipe.

[Lecturer notes down something and instructs the trainee to dismantle the brakes so that he can come back and observe him when he reassembles them.]

[Some 15 minutes later, the lecturer comes to the trainee who has dismantled the brakes.]

Lecturer: We don't have new pads to fit, so we will put back the same ones. How do you know which pad goes where?

[Trainee ponders for some time … looks at the pads … . Shakes his head.]

Trainee: [No response]

Lecturer: [Picks up the two pads] … This one has piston marks … . This one has calliper marks?

Trainee: Oh … [points at the one with piston marks] … this one goes inside.

Lecturer: Give me one advantage and one disadvantage of the disc in a disc brake, compared to brake shoes.

Trainee: [No response] Lecturer: The disc brake cools quicker after braking. Let's say you are going down Malagwane (hill). Because the disc is exposed, it can cool faster, but shoes can end up smelling.

The disadvantage is that when you drive through water and have been using the brakes, the disc can crack.

Lecturer: Now … how is the condition of this disc?

[Trainee uses hand to feel it.]

Trainee: … I think this one requires to be replaced.

Lecturer: Why?

Trainee: It is worn out.

Lecturer: Good. Okay, put back everything and replace the wheel.

[The lecturer observes as the trainee reassembles.]

It should be noted that, while the above practical assessment is on removing and replacing disc brakes, the deliberate focus on each part illustrates the essential need for the identification and naming of each part, understanding its role and how it fits in the brake system, as well as understanding how changing dynamics and conditions affect the functioning of the discs. The extract also clearly shows the foundational use of 'types' along with 'parts', enabling the lecturer to differentiate and contrast different braking systems and also to break down and reassemble one braking system.

Mereological discussion of Automotive Mechanics pedagogy

Part of relations in Automotive Mechanics pedagogy

The crucial role of the way in which parts work in pedagogy was clearly expressed when interviewing the lecturers. VOCTIM1 stated:

> Firstly, I want the student to know the parts; then, I want the student to know the parts that make up the system before knowing the systems that make up the car.

The lecturer's strategy exposes the principle of part–whole relationships inherent in mereology. By teaching students about individual car parts first, then progressing to parts that constitute systems, VOCTIM1 underscores the importance of understanding each component and its function. In this way, students are prepared in order to recognise more intricate interactions as they begin to perceive the car as a whole, echoing the mereological concept of part–whole relationships building up in complexity. Similarly, ECOT1 explained:

> We do one by one. We look at each part alone, and look at the next part, before we look at the parts as a system. Now each system links to the other system. You again look at each part of the next system … part by part … then the system … then look at how this system links to the other system.

This lecturer underscores the principle underlying their teaching, as premised on looking at each part alone, initially in isolation, before moving to the next part, until all the parts are considered together as a system. The principle of part–whole relationship, which aligns with the essence of mereology, allows the complex system of a car to be broken down into smaller, more 'digestible' parts on which students can build so as to manage complexity and gradually build towards an understanding of the whole.

Overlapping parts of Automotive Mechanics pedagogy

The concept of overlapping parts also surfaces in VOCTIM1's teaching method, as elucidated in a separate interview:

> I always teach clutch first … what it does … link engine and transmission … why the car jumps when the clutch is released quickly … the engine goes off because there is no smooth connection with the transmission.

In this instance, the lecturer introduces students to overlapping parts that interconnect to constitute more complex systems. By focusing on the clutch, the engine and the transmission, VOCTIM1 exposes students to shared components that function in multiple subsystems. This exercise brings the mereological 'overlap' concept to the fore and highlights the significance of understanding how overlapping parts operate in unison and individually. Grappling with how the clutch operates with other connected parts is important. If the overlap is working well with other parts, then there will be smoother engagement and disengagement of the engine with the transmission. If the clutch does not overlap properly, there will be jerky shifting or difficulty in changing gears. When understanding what a part is, it becomes important to understand what it overlaps with.

In the lesson transcript on disc brakes, we see the lecturer working with how the disc brakes form overlapping parts of the car's hydraulic system (with how brake fluid and the brake piston work), the thermal system of the car (regarding heat), and the safety system of the car (the danger of a disc brake cracking). But because his first-year students do not yet grasp the basic parts of the mechanical disc brake system, he moves forward and does not elaborate on the overlaps between the different systems and parts.

Transitivity of parthood in Automotive Mechanics pedagogy

Applying the mereological concept of transitivity of parthood becomes more pronounced as the lecturers progressively introduce parts and overlapping parts to complete systems. This process of teaching, involving a gradual transition from parts to systems, allows students to understand how each component is integral to the functioning of the entire system.

Such approach is evident in the teaching method of VOCTIM2, as stated in the interview:

> You start from the part to know the parts that make up the system, then the systems that make up the car.

VOCTIM2 echoes the strategy of VOCTIM1, emphasising that understanding smaller, individual components provides a path to comprehend larger, interconnected systems. By doing so, the transitivity of parthood – a fundamental mereological concept – is mirrored in the lecturers' pedagogical approach.

ECOT1 sums up the teaching of Automotive Mechanics as follows:

> Basically, in Motor Mechanics, you break a car into parts and make a module about these parts, then you teach these parts. So for instance you see the engine as the source of power; now what do you do with the power? You talk about the transmission, the clutch, the gearbox in your Isuzu car, the prop shaft, the diff and how the power is then taken to the wheels.

Thus, essentially, the teaching of Automotive Mechanics is premised on dividing a car into smaller parts that progressively interconnect into subsystems and systems to build towards an understanding of the larger interconnected systems. This pedagogical practice depicts the concept of transitivity of parthood. Transitivity enables the digging down into a fault a car is showing by working down into subsystems, sub-subsystems, and eventually to the individual component, as illustrated in the next section.

Composition and decomposition in Automotive Mechanics pedagogy

Another significant aspect of applying mereology in teaching Automotive Mechanics involves practical composition and decomposition, as was seen in the earlier transcript on disc brakes. This approach involves identifying, disassembling and reassembling the car's systems, as illustrated in the following transcriptions:

VOCTIM1:

> Identifying, disassembling, and reassembling … to know the car, you need to identify parts, disassemble, and reassemble. Assemble the parts to make up the system and assemble the systems to make up the car.

ECOT1:

> I take them there [to the workshop], we dismantle the engine. I show them the parts, then I put the engine together. I encourage them to take pictures using their phones. If you forget, then the picture will remind you how the parts come together. I put the engine together myself, and I let them watch. Next time, I assign group 1 to dismantle the engine; when they do, I come and ask them to identify the parts. I then ask them to assemble the engine again.

The processes that both VOCTIM1 and ECOT1 describe align with the mereological activities of decomposition and composition. Through this method, students experience first-hand how individual parts collectively form a system, further solidifying their understanding of part–whole relationships. These parts and systems interconnect and overlap, making the process of composition and decomposition occur in interrelating chunks. The car makes sense through the build-up of part–whole relationships, interconnection and relations. These activities provide a concrete and tangible way for students to embody the concept of mereology, enhancing their ability to understand the mechanics of a car. Decomposition and composition also give the student first-hand experience of the ways in which these mereological relationships work.

This part–whole relationship, overlapping and transitivity and these composition–decomposition possibilities all point to the hierarchical structure of Automotive Mechanics pedagogy and the usefulness of employing the detailed analytical corpus of mereology for pedagogic analysis.

Routine expertise in Automotive Mechanics pedagogy

One critical vocational outcome in Automotive Mechanics pedagogy is the development of routine expertise. Routine expertise was encouraged in the discussion on dismantling by ECOT1 above, emphasising the repetitive interaction and familiarity with the parts and systems in mastering Automotive Mechanics. This was put as a rule of thumb by VOCTIM1:

> The more you do it, the more you see it, the more you get used to it.

VOCTIM1's comment encapsulates how students can foster expertise and familiarity through constant engagement with parts and systems – concepts at the heart of mereology. This routine expertise forms the basis of students' development, aiming to produce proficient automotive mechanics. Chunking parts into wholes assists directly with developing routine expertise

(Sweller, 1988), as the students can work with the way the systems of the car interrelate rather than struggling with what each part is and does. These vocational outcomes are not static but are continually enhanced through practice and understanding of systems, as ECOT1 indicates:

> … you have not dismantled the parts, but if you are a good mechanic, you try to understand how the parts fit together – even if it takes a long time. A good mechanic will try to understand how the parts work together. You will have things you know, like me, when working with a car; there are things I just know. I still don't know everything. But the things that I know, I know. A good mechanic will have things he knows about cars; he won't know everything, but he has to know certain things, and the more problems you meet when working on a car, the better you will be, and it works to consult other good mechanics when you have a problem [about a car].

In summary, the analysis of the interview data and the lesson transcripts demonstrates that the principles of mereology – the study of part–whole relationships – are deeply ingrained in the teaching of Automotive Mechanics. The analysis reveals that lecturers intuitively employ these principles in their pedagogical strategies, which helps to break down the complex whole into its parts for teaching purposes. From identifying individual parts, understanding the overlapping components, appreciating the transitivity of parthood and developing hierarchical systems to building routine expertise, the application of mereology enhances the understanding of the intricate dynamics of Automotive Mechanics pedagogy.

Process ontology in Automotive Mechanics pedagogy

Many of the quotes used in the mereological analysis have a double face: on the one side, they point to part–whole relations, and, on the other, they show dynamic processes at work.

Engaging with dynamic systems

VOCTIM1 clearly illustrates process ontology:

> I always teach clutch first, what it does, link engine and transmission, why the car jumps when the clutch is released quickly, the engine goes off because there is no smooth connection with the transmission. I talk about the functions of the clutch; when you press the clutch and stop the car, you are breaking the drive from the engine, and the pressed clutch helps the car not to go off.

In this quotation, the clutch is not presented merely as a physical component but as a dynamic entity engaged in constant interaction with other parts of the car. It is not only about what the clutch is but also about what it does in the overall functioning of the vehicle. To understand a clutch fully, the student must grasp what it does: structure and function work together. VOCTIM2 indicated this similarly:

> The more complex topics, like in heavy haulage trucks that carry sugar cane in Swaziland. They use springs at the back where there are concepts like drive thrust and brake thrust … how are they absorbed. Because in these trucks there are springs, fixed shuttle and swinging shuttle. When the truck pulls, we know the drive will start from the clutch to the gearbox, to the propeller shaft to diff. The diff is mounted on the spring through the centre bolt so that when the truck pulls, the diff does not lag behind. Sometimes, the centre bolt, because it is subjected to forces as the truck moves, it wears away, and the diff loosens away; then you see the truck as if it's moving like a crab. Many buses, you see them going sideways, it is because the centre bolt fastening the diff is broken, and the diff has moved.

Here, for trucks, the clutch is not a separate entity but operates in dynamic ways that give a diagnostic reading on how the whole system is functioning and wearing out over time, with all the different parts and systems interacting with one another to get the truck to 'move like a crab'.

Seeing the car as a network of interacting processes

In an observed lesson [Lecturer VOCTIM1] involving a customer's car that was showing signs of overheating, the lecturer's description elaborates on this idea of process ontology. The lecturer moved from part to part, in the engine cooling system of a car, following cost and complexity rules (what is cheapest and easiest first), with the result that the students would use this 'parts approach' to build on their repertoire towards understanding the operation of the engine cooling system.

The process involved looking for leaks in the radiator and the pipes; when none were found, the next step was determining whether the thermostat was performing its role in retaining and releasing water at the correct temperature from the radiator. When the thermostat was found to be okay, two steps remained: the radiator and the cylinder head (in order of cost and complexity). The radiator was taken out for testing and found to be blocked; a new one had therefore to be bought.

Here, VOCTIM1 underscores the dynamic and complex network of processes inherent in the operation of a car's engine cooling system. The car exists dynamically in time, changing and wearing down, needing repairing and replacing, all at different rates in dynamic tension. The engine cooling system is seen as an assemblage of parts, each engaged in complex interactions with the others. Each of these parts, when faulty, affects the overall efficiency of the system, yet each part involves a varying cost and level of complexity when it has to be examined. The student is guided to gradually build up a rich and nuanced understanding of this dynamic system, which requires an understanding of the different parts at the base, but also needs a process-based, dynamic approach that tracks the networked connections to determine the fault.

Dynamic interactions and transformations in setting valve timing

The examples in this section point to how the teaching of Automotive Mechanics involves dynamic interactions and transformations of parts, processes and systems. These interactions and transformations call into play familiarity with and understanding of parts: how each part fits onto the next and how all of them work together to make up a system in play, in movement, in process. Let us consider the following extract from a lesson on setting valve timing by lecturer ECOT1:

> The lecturer moved the 16 students from the Workshop into the demonstration workshop, which houses two engines. One engine is partially cut away to show the clutch assembly, cylinders, camshafts, and prop shaft.
>
> Lecturer [to technician]: Please open the tappet cover, bring Allen key, number 14.
>
> The lecturer then turns the two camshafts at the top of the engine.
>
> Lecturer: Here, we have two camshafts. This one is for the exhaust … and this one is for inlet.
>
> Today we are going to learn how to set the valve timing. [He shows the students the timing belt.]
>
> Many times, when the timing belt is torn, the car will refuse to start. What many drivers will do is keep starting the car many times, hoping it will eventually start. What is happening when you do that, from my experience, is the following: the valves will bend. Why? Because the camshaft is not turning. When you crank, you move the pistons, and they hit against the valves, which are not in sync. Remember, the valves are moved by the camshaft, and the camshaft is moved by the timing belt.
>
> If the valves have been fitted, you now need to set the valve timing.

In the extract, the lecturer simulates a situation where a car can be brought in to a garage for repairs after its valves have been bent. To contextualise this situation, he explains a series of interactions and transformations that can result from a torn timing belt. A driver, unaware that a timing belt is torn, or perhaps not even conscious of what it is for, keeps trying to start the car many times, hoping it will eventually run. What this driver is doing, as they crank, is moving the pistons. The pistons hit against the valves, which are now out of sync because the camshaft should move them. Yet the camshaft cannot move the valves because a timing belt controls this.

The above components of a valve timing system constitute a fully interacting and functional system. Yet, the breakdown of just one part, the timing belt, brings about a transformation that makes the system dysfunctional and 'transforms' and 'disables' the other components. The camshaft, which controls the valves so that they are in sync with the pistons, cannot turn because there is no timing belt to turn it. The valves are now not synchronous with the movement of the pistons. They hit against the pistons and bend. Hence the setting of the valve timing should follow a series of repairs that correct each part of the valve timing system: the replacement of bent valves and of the timing belt. This setting fine-tunes the dynamic interactions so that the system will once again run optimally.

The above reflections demonstrate the grounding influence of mereological parts playing out in dynamic and changing ways. With each level of teaching – from identifying individual parts to understanding their overlap in different systems to problem-solving and fault finding – the role of part–whole relationships in dynamic processes becomes increasingly vital. This mereological underpinning combined with a process ontology sensitivity enables students to appreciate the intricacies of a motor vehicle as a comprehensive system, setting the stage for a deeper understanding of Automotive Mechanics and the dynamic process involved.

Cognitive load theory in Automotive Mechanics pedagogy

Extending beyond the ontological structure of Automotive Mechanics pedagogy has tangible implications for improving teaching and learning using learning science in general and cognitive load theory (CLT) specifically. This can be stated in intuitive terms. Students must remember many parts, subsystems and systems in a dynamic process, resulting in massive strain on their ability to learn how to be a mechanic. However, chunking simplifies things (Sweller, 1988), where several parts come together and can be worked with as one whole (not as many different parts). Chunking enables students to start to work with the subsystems of a motor vehicle as one thing, not as a whole bunch of parts working together. Chunking enables them to work with the way subsystems work with other subsystems, and so they do not have to focus on all the parts of each subsystem simultaneously.

The key reason why this is important is that our short-term memory can hold only a limited amount of information or a limited number of units, famously captured in this quotation: 'The magical number seven, plus or minus two, refers to the number of chunks of information that can be held in short-term memory at any one time' (Miller, 1956:96). The hierarchical structure of Automotive Mechanics pedagogy allows students to simplify a complex interaction of many parts into one system and focus on the way the system works as one unit. The hierarchical structure can then be built upwards and downwards and across dynamically (Sweller, Van Merriënboer & Paas, 1998). Central to this insight is the way in which chunking reduces the cognitive load students have to work with; rather than many parts that overwhelm working memory, students can work with one system, made up of many different parts that coalesce into one chunk (Hugo, 2016:72–86).

Intrinsic load and the complex nature of Automotive Mechanics

Intrinsic cognitive load pertains to the inherent complexity of the information being learned. For example, Automotive Mechanics, with its wide array of parts and systems, can be intrinsically demanding. The following extracts from an interview with lecturer VOCTIM2 indicate the challenges he faces as he handles the complexity of information:

> Today's cars are advanced; they have sensors for the car not to hit something, for example – electronics.
>
> I first explain components and function, identify components, their purpose in the vehicle, then I move into details, then remedies, e.g. wheel alignment. I do this to help the trainee's understanding. I decide on my own to move from the simple to the complex. If I do that, the students can put all the simple techniques together and apply them to solve a problem in the car.
>
> In fuel injection, this topic is difficult. I teach when I see they are confused. I give an exercise where they will discuss this to help clarify what I was teaching. If they don't [respond well], I have to repeat, maybe slow down, and teach in smaller bits.

In dealing with the inherently complex nature of the processes and interrelationships in Automotive Mechanics, the lecturer faces the arduous task of deciding how best to present information to the student so that the intrinsic cognitive load is better managed. Newer cars are advanced and 'have sensors' and 'fuel injection' – these systems become a 'load' that is intrinsic in their teaching. In this context, there has to be the continuing development of a strategy to move from simple to complex; to let students put together the simple techniques and apply them; to repeat; to slow down; and to teach in smaller chunks.

As VOCTIM1 states in an interview:

> Firstly, I want the student to know the parts, and then I want the student to know the parts that make up the system before knowing the systems that make up the car.

Similarly, another lecturer, ECOT1, indicates in an interview:

> You again look at each part of the next system, part by part, then the system, then look at how this system links to the other system.

Here, VOCTIM1 and ECOT1 are articulating a strategy of managing intrinsic cognitive load by breaking down the complex subject matter into manageable chunks. By beginning with individual parts and gradually moving on to systems, VOCTIM1 reduces the inherent complexity of Automotive Mechanics, allowing students to process and understand the information sequentially and cumulatively.

Extraneous load and the role of teaching methodology

Extraneous cognitive load is associated with the way information is presented to students. For example, the teaching method can either unnecessarily increase or efficiently decrease cognitive load. In situations where extraneous cognitive load increases cognitive load and negatively affects learning, the lecturer has to provide interventions that will benefit the student. Lecturer ECOT1 presents such a setting:

> … sometimes, you come to teach just theory but find that the students don't follow anything. You have to move the class to the workshop to show them models. Sometimes, many times, you have to dismantle individual small parts, then put them … together [again], and then let them do the same in groups before some can even [gain] some understanding.

The above exemplifies the space that an Automotive Mechanics lecturer operates in when consciously examining their role in relation to extraneous load, stepping away from a high extraneous load towards a more effective demonstration method that enhances the grasping of complex information. In having to 'abandon' a theory class for the workshop, where a model is dismantled into individual parts and put together again a number of times, the lecturer enhances the students' understanding of a complex system by moving away from less efficient ways of teaching at a certain stage (theory) to a more efficient way (demonstrating) at that particular point.

Germane load and the formation of schemas

Germane cognitive load is devoted to processing, constructing and automating schemas. In other words, it is the mental effort of creating long-lasting knowledge structures. The example quoted by Lecturer ECOT1 demonstrates the struggle where sometimes the students

> [d]on't follow anything. You have to move the class to the workshop to show them models. Sometimes, many times, you have to dismantle to individual small parts, then put them … together [again], and then let them do the same in groups before some can even [gain] some understanding.

The long, slow process of building meaningful schemas is clear in the above quotation. Seeing and handling the models, identifying their constituent parts, putting the parts together, and repeating the process are all part of the formation, processing, construction and automation of schemas – where the student internalises new information in a way that can be used later on.

As VOCTIM1 stated:

> The more you do it, the more you see it, the more you get used to it.

Both quotations allude to the importance of repetition and practice in encouraging the development of schemas. Students can better form mental models of how these elements work together by repeatedly interacting with the parts and systems. This engagement increases the germane load, facilitating deeper learning and mastery of Automotive Mechanics.

Germane load and the formation of schemas are vital to developing diagnostic abilities, where a fault in a motor vehicle has to be tracked through various problem-solving strategies. The fault has to be traced, with any spill-on effects understood in the various subsystems of the vehicle. We saw this earlier in our discussion of valve timing settings and the radiator leak:

> The valves will bend. Why? Because the camshaft is not turning. When you crank, you move the pistons, and they hit against the valves, which are not in sync. Remember, the valves are moved by the camshaft, and the camshaft is moved by the timing belt.

Similarly, VOCTIM1 demonstrated to students how to track and solve the overheating problem in a customer's car by systematically tracing the problem, starting with simple leaks, then the thermostat, then the radiator and cylinder head. This gives the students a schema to use to fault-find when presented with an overheating problem.

If the students in Automotive Mechanics do not get a chance to engage fully with germane load and schema construction, their very purpose as car mechanics is threatened. This leads us to the heart of how material inference (Brandom, 2000) is used in diagnostic problem-solving – a second key dimension of Automotive Mechanics pedagogy, which is the subject of another article.

Conclusion

The analysis presented in this article indicates that the instruction of Automotive Mechanics can be significantly understood and enhanced by using ontological categories to support analysis. To put it plainly: both vocational education in general and Automotive Mechanics education specifically engage with things and processes that perform functions; hence the relevance of ontology – the study of how the world is composed – as an aid to learning. Mereology, which examines part–whole relationships in ontology, forms the bedrock for analysing part–whole relations in automotive pedagogy. The findings suggest that the common lecturer tactic of deconstructing a motor vehicle into its component parts for instructional purposes resonates strongly with the ontological categories. Students initially learn about the separate parts of a vehicle, comprehending their essential characteristics and functionalities. This part-centred approach is also vital when these components are assembled into systems, disassembled and reassembled again, which fosters a broader understanding of a vehicle's overall operation. The concepts of part-of, overlap and transitivity of parthood in mereology offer a valuable initial lens through which to appreciate the pedagogical decisions made by the lecturers. Importantly, it resonates with the existing pedagogic practices of these lecturers. They do not have any issues with the way parts and wholes work – it is, after all, their bread and butter or, more aptly, the nuts and bolts of their practice.

Adopting Whitehead's perception of reality as fundamentally processual, process ontology provides an abstract means of comprehending the dynamic transformative elements of automotive pedagogy. Teaching is not merely about static parts and systems; it is also about the ongoing processes that occur in and between these components and systems. An in-depth comprehension of part–wholes and processes is required for diagnostics, a critical process-oriented activity aimed at identifying non-functional parts. Frequently, mechanics encounter customers entering the workshop with automotive problems that need to be identified and resolved. A companion paper will outline the way material inference (Brandom, 2000) is a crucial concept required to engage theoretically with this essential dimension of Automotive Mechanics pedagogy.

Cognitive load theory (CLT) is particularly relevant in mereology, where the understanding of a motor vehicle evolves from parts to wholes. Segmenting the complex whole into smaller parts is an essential strategy in managing intrinsic cognitive load. By initially learning about individual components, students diminish the cognitive demands of understanding the system when these parts are subsequently combined. This method reduces intrinsic load and creates space for germane cognitive load, which directly aids learning.

Extraneous cognitive load can be mitigated by sequencing practical instruction in ways that echo the part–whole structure intrinsic to Automotive Mechanics. This approach capitalises on 'chunking', where each part becomes a manageable piece of information that, once mastered, can be connected to other chunks so as to form a coherent whole. Reducing extraneous cognitive load enables students to allocate more cognitive resources to germane processes, in this way fostering deeper learning and problem-solving.

By harnessing the part–whole structure and dynamic interactions essential to Automotive Mechanics, lecturers can strategically manage cognitive loads, in the process optimising students' engagement, understanding and problem-solving capacity. Cognitive load theory can work synergistically with mereology and process ontology to enrich pedagogical practices in teaching Automotive Mechanics and facilitate detailed theoretical analysis of subject-specific vocational pedagogies. This extends the rich field of current research on using cognitive load theory for teaching (Tindall-Ford, Agostinho, & Sweller, 2020; Kirschner & Hendrick, 2022). The practical implications are immense, with many well-established ways to improve learning using specific strategies, such as worked examples, goal-free effect, reducing the problem space, dual coding, the expertise reversal effect, spaced practice and metacognition, to mention only a few (Hugo, 2016; Kirschner & Hendrick, 2016, 2022). We shall explore these implications for vocational education in a subsequent article.

While this article focuses specifically on Automotive Mechanics pedagogy, the findings and pedagogic approaches are undoubtedly transferable to other disciplines in the vocational domain. At the University of KwaZulu-Natal, the first author and a group of master's students have analysed more than 150 videos from various subjects in the TVET curriculum and identified the frequent use of ontological categories by lecturers (part/whole, general/specific, type/token, structure/function). These categories resonate strongly with other current analytical traditions that are gaining traction in South Africa, such as legitimation code theory and its use of semantic gravity and semantic density (Maton & Chen, 2016; Rusznyak, 2021), expanding into interesting avenues for collaboration and further theoretical development.

Postscript

The reader may question the use of the term 'vocational pedagogy' as opposed to 'vocational andragogy', especially considering Malcolm Knowles' assertion that adults and children learn differently (Knowles, 1980). Adults often prefer self-directed learning, problem-solving and practical, applicable knowledge. This approach aligns well with the work-oriented focus of vocational education.

Despite these considerations, this study employed the expression 'vocational pedagogy' for several reasons. First, it is the term commonly used in the recent literature, both internationally (Lucas, Spencer & Claxton, 2012) and in South Africa (Blom, 2016). Second, over time, the term 'pedagogy' has broadened its scope to include not only children but also adults, making it more generic. Finally, vocational education frequently employs a blend of direct instruction and problem-based methodologies. Therefore, even though 'vocational andragogy' might seem theoretically more accurate, 'vocational pedagogy' remains the more accepted term, reflecting both historical and current usage, blended teaching approaches and the evolved semantics of the word 'pedagogy'.

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