Implementing hybrid problem-based learning in Mechanical Technology to enhance pre-service teachers' self-directed learning

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Ethics numer NWU-00484-17-A2

Thesis accepted for the degree Doctor of Philosophy (PhD) in Curriculum Studies (CRSE971) at the North-West University

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Graduation: July 2020

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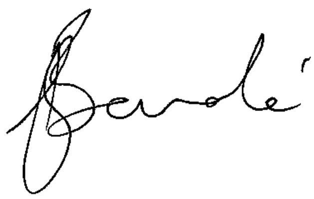

Datum / Date

28/04/2020

ACKNOWLEDGEMENTS

My sincere thanks and appreciation to the following institutions and individuals:

Me. Arina Potgieter for typing, transcribing, recording, photographing and checking of references. Also for standing in as a part-time lecturer during my study leave.

All students taking part in the intervention and participating in the qualitative and quantitative research for your honesty, openness, and patience.

Zine Sapula for helping with EndNote. Without you, I would not have mastered EndNote.

Petra Gainsford for your help with the MS Word template.

Nicole Claassen for your help with Atlas .ti™.

Jackie Viljoen, for the proofreading and editing of this document.

My Dean and Director for approving my study leave.

My colleagues, Kobus Havenga and Arno Combrinck from the subject group Technology, for your help with some of my classes during my study leave, the WILL assessments and general support. A special word of thanks to my colleague, Albert Kemp, and his assistant, Juanta Fick, who were always willing to help me with general computer hickups.

My children, Sanmari and Zias van Zyl, Johan and Marlie Benade as well as Sanet and Stephan Downey who always believed in me.

My grandchildren, Rihane, Juan, Mienke, Gerdalize, Zimari and Liam.

My daughter, Sanet 'Polla', for helping with language editing. Without your support this would have been impossible.

My lovely supportive, understanding, patient, helpful and always present wife, Doctor Trudie Benade. Without you, this could not have happened.

My dear mother, Susan, who sadly passed away halfway through this study. Thank you for always encouraging me in a way that only a mother can.

My study leader, Professor Marietjie Havenga. Thank you for your hard work and endurance.

My God and Father in heaven. Without You, I am nothing and not able to do anything good. Thank You for Your grace, blessings, and protection over the past 62 years.

ABSTRACT

IMPLEMENTING HYBRID PROBLEM-BASED LEARNING IN MECHANICAL TECHNOLOGY TO ENHANCE PRE-SERVICE TEACHERS' SELF-DIRECTED LEARNING

The aim of this study was to investigate whether the implementation of hybrid problem-based learning (hPBL) in practical Mechanical Technology (MT) classes as part of the teacher education curriculum, could foster students' self-directed learning (SDL). A pragmatist approach directed this research study and a mixed method methodology was followed.

The Williamson questionnaire for self-directed learning was used as quantitative research instrument (twice as a pre-test and twice as a post-tests) while the qualitative data collection involved focus group meetings, interviews, project sheets and observations. The data of the qualitative research was analysed by means of ATLAS.ti™. The research project took three years and was planned according to design-based research principles, which included two cycles (interventions) that occurred during the second semester of 2017 and the first semester of 2018. At the start of the project in 2017, all participants (second-year Mechanical Technology Automotive students) (N=12) completed the Williamson test (pre-test 1). Thereafter, participants were subjected to a one-hour exercise with regard to basic PBL skills to familiarise them with the interventions that would follow. Participants were randomly selected to work in two groups with six teams (2 to 3 members in a team) and started with the first intervention comprising two projects, one auto-electrical and one mechanical project. The duration of the first intervention was more or less 12 weeks and ended with the completion of the Williamson post-test (post-test 1). The second intervention in 2018 followed a similar design including a second 12-week intervention comprising two similar projects, a Williamson pre-test (pre-test 2) and a post-test (post-test 2). Students developed and finished four projects in more or less 24 weeks by means of applying hPBL.

Although results of the Williamson questionnaire indicated an improvement in some of the participants' SDL abilities, the qualitative data clearly indicated various exemplars where students enhanced their SDL skills in the MT practical tasks. Finally, a model for implementing PBL in Mechanical Technology was developed as based on the integrated results.

Keywords: Hybrid problem-based learning, Mechanical Technology, problem-based learning, teaching students, self-directed learning.

OPSOMMING

Die doel van hierdie studie was om te ondersoek of die implementering van hibridiese probleemgebaseerde leer (hPBL) in praktiese Meganiese Tegnologie (MT) klasse as deel van die kurrikulum vir onderwysers, die studente se selfgerigte leer (SDL) kan bevorder. ŉ Pragmatistiese benadering het hierdie navorsingstudie gerig en 'n metodologie met gemengde metode is gevolg.

Williamson se vraelys oor selfgerigtheid is gebruik as 'n kwantitatiewe navorsingsinstrument (twee keer as 'n voortoets en twee keer as 'n na-toets) en die kwalitatiewe data-insameling het fokusgroepbyeenkomste, individuele onderhoude, projekstate en waarnemings behels. Die data ontleding van die kwalitatiewe navorsing is met behulp van ATLAS.ti™ gedoen. Die navorsingsprojek het drie jaar geduur en is beplan volgens ontwerpgebaseerde navorsingsbeginsels (design-based research) wat twee siklusse (intervensies) ingesluit het wat gedurende die tweede semester van 2017 en die eerste semester van 2018 plaasgevind het. Aan die begin van die projek in 2017 het alle deelnemers, die tweedejaarstudente in Meganiese Tegnologie-motor (N=12), die Williamson-toets (voortoets 1) afgelê. Daarna is deelnemers aan een uur se oefening met betrekking tot basiese PBL-vaardighede onderwerp om hulle vertroud te maak met die intervensies wat daarop sou volg. Die deelnemers is lukraak gekies om in twee groepe met ses spanne (2 tot 3 lede in 'n span) te werk en het toe begin met die eerste intervensie wat bestaan uit twee projekte, een outo-elektriese en een meganiese projek. Die duur van die eerste intervensie was ongeveer 12 weke en het ge-eindig met die Williamson-toets (na-toets 1). Die tweede intervensie in 2018 het op 'n soortgelyke ontwerp gevolg, waaronder 'n tweede intervensie van 12 weke wat bestaan het uit twee soortgelyke projekte, sowel as ‘n Williamson-voortoets (voortoets 2) en na-toets (na-toets 2). Studente het vier projekte in ongeveer 24 weke met behulp van hPBL ontwikkel en voltooi.

Alhoewel resultate van die Williamson-vraelys ‘n verbetering in die SDL van sommige deelnemers aangetoon het, het die kwalitatiewe bevindings duidelik verskillende voorbeelde aangetoon waar studente hul SDL-vaardighede in die MT-praktiese take verbeter het. Laastens is 'n model vir die implementering van PBL in Meganiese Tegnologie ontwikkel, gebaseer op die geïntegreerde resultate.

Sleutelwoorde: Hibriede probleemgebaseerde leer, Meganiese Tegnologie, probleemgebaseerde leer, onderwysstudente, selfgerigte leer.

LIST OF ABBREVIATIONS AND ACRONYMS

C2005	Curriculum 2005
CAPS	Curriculum and Assessment Policy Statement
CL	cooperative learning
CT	Civil Technology
CTE	Career and Technology Education
DBE	Department of Basic Education
DBR	Design-based Research
DoE	Department of Education
EduREC	Faculty of Education Ethics Committee
EGD	Engineering Graphics and Design
ET	Electrical Technology
FET	Further Education and Training
GET	General Education and Training
hPBL	hybrid problem-based learning
IOL	Independent Online
MSE	mean squared error
MT	Mechanical Technology
MTA	Mechanical Technology Automotive
MTE	Mechanical Technology Education
NCS	National Curriculum Statements

NQF	National Qualifications Framework
NWU	North-West University
OBE	Outcome-based education
PAT	practical assessment task
PBL	problem-based learning
PBLC	Problem-based Learning Curriculum
PBP	problem-based project
PCK	pedagogical content knowledge
PoBL	problem-organised Learning
POPI	Protection of Personal Information (Act)
RTO	Registered Training Organisations
SADTU	South-African Democratic Teachers Union
SDL	self-directed learning
SDLRS	Self-Directed Learning Readiness Scale
SRL	self-regulated learning
SRSSDL	Self-Rating Scale of Self-Directed Learning
STEM	Science, Technology, Engineering and Mathematics
TAFE	Australian Technical and Further Education
TE	Technology Education
THCSDL	transformative and holistic continuing self-directed learning
TVET	Technical and Vocational Education and Training

UBE	Universal Basic Education (Nigeria)
VET	Vocational Education and Training
VTE	Vocational and Technical Education

Table of content

List of Tables

List of Figures

CHAPTER 1: THEORETICAL BACKGROUND AND PROBLEM STATEMENT

1.1 Background and problem statement

As a result of the information revolution of the 21st century, individuals need to focus on "continuous, lifelong learning" and the solving of "real-world" problems (Guglielmino, 2013:291; Hesse *et al.*, 2015; Trilling & Fadel, 2009:116). In order to help prepare students for the above-mentioned demands, higher education institutions need to provide active teaching–learning environments, rather than passively providing information to students as usually happens in traditional classroom settings (Loyens & Rikers, 2011; Wolfe, 2010). Active learning environments intend to challenge students regarding knowledge construction rather than knowledge acquisition (Mojavezi & Tamiz, 2012).

A self-directed learning (SDL) environment can support students in developing abilities to manage their learning activities and monitor their own learning achievements (Kim *et al.*, 2014). Students need to function as self-directed learners[1] in order to encounter the demands of the fast-changing workplace where emphasis is placed on finding solutions to problems and working in collaboration (Guglielmino, 2013). This statement made by Guglielmino is also relevant for Mechanical Technology (MT), as the technological environment is also constantly changing.

With regard to the requirements for teacher education, pre-service teachers need to develop self-directed learning abilities for the 21st century, be prepared for challenges of the fourth industrial revolution, and be able to implement skills in their classes that will aim to enhance learners' active and responsible learning (Collins & Halverson, 2018; Department of Education [DoE], 1997). This can be linked to Alvin Toffler who, in his book Future shock (1971), said, "[t]he illiterate of the 21st century will not be those who cannot read and write, but those who cannot learn, unlearn, and relearn" (Toffler, 1971:21). Active responsible learning refers to the process where students engage with their learning in such a way that they transform from passive to active learners in order to deepen their understanding of a specific subject (Bean, 2011). Aligning preparation of MT

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1 Although the term 'learner' usually refers to a school learner and the term 'student' to a tertiary learner, in this study (in most cases) both terms are used to describe learners or students in a tertiary learning environment.

pre-service teachers with the subject-specific requirements implies that they should be equipped with teaching and learning knowledge, skills, abilities and relevant strategies to address practical tasks as well as to teach theoretical topics among others (Benade, 2016; Department of Basic Education [DBE], 2014a).

In South Africa, most research with regard to Technology education and related subjects was done on managerial matters, implementation difficulties and safety concerns (Ramdass, 2009). Although the Practical Assessment Task (PAT) documents from the DBE do provide clear guidance with regard to practical Mechanical Technology (MT) tasks for Grade 12 learners, there are no clear guidelines for the development of MT students' practical tasks in higher education. Furthermore, the North-West University (NWU) is the only university in South Africa offering MT for pre-service Technology teachers. As a result, there is a gap in current research. From the literature overview, it became apparent that there is no clear guidance concerning the teaching and learning of future MT pre-service teachers with regard to practical competencies to enhance their SDL. Currently, the development of MT teachers' practical skills mostly relies on simulations of real-world practical scenarios and experiences.

Problem-based learning (PBL) is a well-known student-centred approach that can assist students in developing self-directed learning (Shinde & Inamdar, 2013; Veldman *et al.*, 2008; Wijnia *et al.*, 2011). According to Suwono and Dewi (2019:02), "PBL consists of five to seven phases, namely developing and presenting artefacts, exhibiting, analysing and evaluating the problem-solving process". The use of PBL may be an appropriate strategy to be used in MT practical tasks, as according to Podlesny and Kozlov (2013), PBL can be used as a reflection of industry-related real-world experiences. PBL may also be useful in helping students to become self-directed students (Beavers, 2009; Cottrell, 2013). PBL is based on a question of inquiry and may be *organised* around the development of full-scale projects and real-world problems (De Graaff & Kolmos, 2007). Moreover, PBL involves that students solve a problem in collaborative groups, take "ownership for learning", and "engage in self-directed learning" (Savery, 2015:8). It can be argued that active learning approaches such as SDL contribute to the development of independent learning and the student's ability to apply knowledge to new learning experiences (Jones *et al.*, 2013; Wang & Cranton, 2012). An SDL environment may also be useful in addressing challenges, such as some students losing interest, doing rote learning, being unmotivated, having problems linking theory with practice and not being able to solve problems (Azer *et al.*, 2013 ; Kim *et al.*, 2014). Current pre-service teachers should thus be able to develop essential knowledge and self-directed skills for future demands.

1.2 The rationale for this study

- is to equip students with knowledge, skills and strategies to address practical Mechanical Technology tasks;
- prepare students to manage their own learning processes;
- introduce problem-based projects as part of the teacher training curriculum in Mechanical Technology; and
- enhance pre-service Mechanical Technology teachers' self-directed learning with regard to practical work (develop a theoretical framework).

1.3 Research questions and aims

The main research question was:

How can the implementation of hybrid problem-based learning in Mechanical Technology enhance pre-service teachers' self-directed learning?

The sub-questions were the following:

1. What does Mechanical Technology, problem-based learning and self-directed learning entail?
2. How can the implementation of hybrid problem-based learning in Mechanical Technology enhance pre-service teachers' higher-order thinking, practical knowledge and skills in the automotive discipline?
3. To what extent can pre-service Mechanical Technology teachers enhance their self-directed learning in a problem-based context?

The questions were answered by means of a thorough literature review and by empirical research.

The main aim of this study was to determine how the implementation of hybrid problem-based learning in Mechanical Technology could enhance pre-service teachers' self-directed learning.

The sub-aims were:

1. to understand what Mechanical Technology, problem-based learning, and self-directed learning entail;
2. to determine how the implementation of hybrid problem-based learning in Mechanical Technology can enhance pre-service teachers' higher-order thinking, practical knowledge and skills in the automotive discipline;
3. to determine to what extent pre-service Mechanical Technology teachers can enhance their self-directed learning in a problem-based context.

The following keywords as outlined in Table 1.1 were used in this study: self-directed learning (SDL), problem-based learning (PBL), hybrid problem-based learning (hPBL), Mechanical Technology (MT), Mechanical Technology Automotive Discipline (MTA), Mechanical Technology Education (MTE), and problem-based project.

Table 1:1: Clarifications of terminology

Clarification of terminology keywords	Definition	Source
Self-directed learning (SDL)	Self-directed learning is *"a process in which individuals take the initiative, with or without the help of others, in diagnosing their learning needs, formulating learning goals, identifying human and material resources for learning, selecting and implementing appropriate learning strategies, and evaluating learning outcomes".*	Knowles (1975:18)
Problem-based learning (PBL)	*"Problem-based learning provides students with authentic and meaningful problems that can serve as a springboard for inquiry and arithmetic which end with reflection". Depending on which model is referred to, problem-based learning involves five to seven phases.*	Suwono and Dewi (2019:2)
Hybrid problem-based	In hPBL, the tutor or facilitator guides students through mini-lecturers, demonstrations, practical classes, and learning resources. In addition,	Kahn and O'Rourke (2005), Smith

Clarification of terminology keywords	Definition	Source
learning (hPBL)	students may develop a practical project based on a problem of inquiry. The tutor may intervene more or less 30% in hPBL.	(2005) and Walker *et al.* (2015)
Mechanical Technology	"*Mechanical Technology focuses on concepts and principles in the mechanical (motor, mining, shipping, rail, power generation, etc.) environment and on technological processes. It embraces practical skills and the application of scientific principles. The subject aims to create and improve the engineering and manufacturing environment to enhance the quality of life of both the individual and society alike, and ensure the sustainable use of the natural environment and resources."*	DBE (2014a:9)
Mechanical Technology Automotive (MTA) discipline	The specific focus in this study is on the Automotive discipline. *"The automotive discipline focuses on petrol- and diesel-engine driven vehicles with regard to the automotive industry and modern automotive engineering."*	DBE (2014a:10)
Mechanical Technology Education (MTE)	In this context, Mechanical Technology Education involves "*the understanding of how people learn, how to teach, understanding of pedagogical content knowledge, language, culture, community, as well as management of classroom activities, application of communication skills, use of technology, and reflection on one's own performance*".	Britzman (2012:1–19) and University (2018)
Problem-based project	*"A problem based on a question of inquiry and structured around the development of a project".*	Throndahl *et al.* (2018:430).

An extensive literature study was undertaken, which formed the basis of the research. Literature searches were conducted on EBSCOhost, ERIC, catalogues of South African and international university libraries, Google Scholar and the World Wide Web.

1.4 Overview of relevant literature

This subsection contains a brief overview of the key concepts regarding self-directed learning (SDL), problem-based learning (PBL), the Mechanical Technology subject (MT) and educating or training[2] of Mechanical Technology pre-service teachers.

1.4.1 Self-directed learning

Knowles (1975:18), a pioneer with regard to SDL, mentions that self-direction is a learning process in which the student undertakes self-planned learning by taking control of the process, as he puts it: "planning and deciding one's learning" as the major aim of SDL. Knowles (1975:18) also states:

> *In its broadest meaning, self-directed learning describes a process in which individuals take the initiative, with or without the help of others, in diagnosing their learning needs, formulating learning goals, identifying human and material resources for learning, choosing and implementing appropriate learning strategies, and evaluating learning outcomes.*

This was further confirmed by Andersen (2013) who stated that an SDL student is an autonomous learner who is able to identify his[3] learning needs when he comes across a problem to be solved, information to be obtained or a skill to be acquired. In short, SDL refers to the ability to learn how to learn (Cordon, 2015; Guglielmino, 2013; Stolk *et al.*, 2010).

The benefits of SDL are best described in terms of the student it develops. Zhang *et al.* (2012) describe self-directedness in students as their abilities to show initiative, independency, persistency, responsibility and a tendency to view problems as challenges. They are also self-disciplined, demonstrate a high degree of curiosity, feel a strong desire to learn, are able to organise their own time and set an appropriate pace for learning (Abraham *et al.*, 2016; Bagdonaitė-Stelmokienė *et al.,* 2016). Self-directed students act with self-confidence, they have the ability to develop a plan for completing the work and at the same time, they enjoy their work (Beavers, 2009; Seifert *et al.*, 2016).

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[2] Although the term 'training' relates to learning manual labour or skills it is often used in this study to explain the detail of educating MT teachers.

[3] In this study the masculine gender is used, however it does not exclude the feminine gender.

Furthermore, self-directed students prefer active participation and continuously evaluate their own progress, they are risk-takers, and they know how to gather resources and how to use them to construct knowledge (Hattie, 2012; Shannon, 2008). Gregory and Chapman (2012) as well as Lee *et al.* (2010) support this view and add that, for self-directed students, learning can be easier since the students take ownership of their own learning. Furthermore, recent studies show that if students apply specific SDL skills, most of them will benefit by doing so, as SDL can enhance the development of life-long learning, self-assessment and analytic thinking (Murad *et al.*, 2010).

Korthagen (2010) also highlights that learning is not an isolated action, but should take place in association with an educator, tutor and peers. Karavoltsou and O'Sullivan (2011) agree and emphasise that, despite the autonomous nature of self-directed students, they need to interact with fellow students to exchange valuable information. Thus, the learning continuum shifts from an educator-directed scenario to a self-directed scenario and collaboration in group work (Jossberger, 2011; Loyens *et al.*, 2008; Thomas *et al.*, 2016).

In an SDL environment, the lecturer acts as a facilitator who guides the students in such a way that they take ownership of their learning processes (Schmidt *et al.*, 2011). Baran *et al.* (2011) point out that the role of the facilitator is to listen, reflect, facilitate and empower. SDL thus provides various benefits to the student as it allows more freedom to explore resources and provides a high level of work satisfaction (Schmidt *et al.*, 2011).

Since the technology process is usually triggered by a problem or a need, Kurniawati (2016) and Barak (2011) agree that PBL is an appropriate strategy for enhancing SDL in engineering and related disciplines. In this study, PBL will be applied in the class as appropriate teaching and learning strategy where MT students need to develop automotive-related problem-based projects in teams.

1.4.2 Problem-based learning

PBL is a teaching–learning strategy that can enhance students' self-directed learning and develop high-order thinking skills (Savery, 2015). PBL is based on a question of inquiry, a challenge or a driving problem to be solved (Davies *et al.*, 2011; Walker *et al.*, 2015). According to Hung *et al.* (2008:486), PBL in the tertiary curriculum is "*a form of education in which information is mastered in the same context in which it will be used*", meaning that PBL is a teaching method that initiates students' learning activities by generating a need to solve a real-world and ill-structured problem. PBL was introduced and successfully used in the late 1960s in the preparation of medical doctors at McMaster University in Canada and was also implemented during the late 1970s in Denmark for the preparation of engineers (Kolmos & De Graaff, 2014). Since the 1960s, the use of PBL in the university curriculum as a teaching–learning strategy allows students to develop various skills and links theory with practice (Bean, 2011; Jones *et al.*, 2013). Studies established that SDL is a developmental process that can be fostered by PBL (Loyens *et al.*, 2008). Choo *et al.* (2011) emphasised that PBL supports the active learning of students.

Moreover, PBL is a teaching approach that necessitates strong social participation and collaboration and emphasises responsible learning as involved in SDL (Havenga, 2015). PBL requires students to engage with the problem in groups in order to solve real–world problems, to address a question of inquiry or to develop an artefact or model. Since most projects include vagueness with regard to time, cost, resources and hidden difficulties, it is essential to manage projects as well as team members involved in project development effectively.

Characteristics of PBL include the following: PBL is student-centred, empowers students to do research, integrates theory with practice and applies knowledge and skills when solving problems (Savery, 2015; Sim *et al.*, 2011). Jones *et al.* (2013) identified four general principles central to PBL. They state that in order for students to be effective, students need to set appropriate goals, use scaffolding that can support learning, apply frequent self-assessment, and apply self-management to promote individual and group participation. In PBL, the lecturer or teacher acts as a facilitator who guides and supports students to solve ill-structured real-world problems. Another important characteristic of PBL is role shifting, where the students alter from being inactive receivers of knowledge to being active creators of knowledge, and the lecturer alters from a lecturer transmitting knowledge to a facilitator who guides the students through the learning process (Dahms & Zakaria, 2015; Kenney, 2008).

Although PBL is characterised by seven operational steps (see Table 5.3 and Figure 2.3 and 2.4), a PBL intervention should be based on a problem of inquiry and could be *structured*[4] around the development of a project (Dahms, 2015). Hybrid PBL (hPBL) as used in this study is to some extent similar to the Aalborg PBL and Maastricht PBL models. HPBL comprises seven steps and provides for the use of ‘mini-lectures’ that the instructor can use to guide students. As the participants in this study were unfamiliar with any form of PBL, the researcher therefore argued that hPBL should be an appropriate approach to introduce students to PBL (see 2.4).

In recent studies, it was established that hPBL was preferable to traditional PBL in launching knowledge and problem-solving skills, as the hPBL format offers a unique prospect for the simultaneous use of traditional teaching–learning methods, such as mini-lectures as well as PBL practices without losing any of its distinctive benefits (Lian & He, 2013; Samarasekera & Karunathilake, 2011). These researchers also found hPBL a novel design for effective small group learning. In addition, Dahms and Zakaria (2015), as well as Masek and Yamin (2010), found hPBL a useful approach when students are required to develop projects while being subjected to a combination of interactive mini-lectures and practical work. According to Ahmadi and Sajjadi (2013), a mini-lecture is an engaging, enjoyable way to interact with students in 10 – 15 minutes. They are well planned, interactive ‘lessons’, requiring research and proper planning on the lecturer’s side (Ahmadi & Sajjadi, 2013).

As the current study was about the implementation of hPBL in MT, an overview of MT will be given in the following subsection.

1.4.3 Mechanical Technology education

Technology Education (TE), including MT, involves technological knowledge and skills, as well as technological practices (DBE, 2014c). TE and related subjects deal with technological processes integral in the development and provision of goods, services and structures in order to improve the quality of life as well as understanding the impact of technology on both the individual and society (Beniger, 2009; Randewijk & Swart, 2006). The innate nature of Technology presents itself as a problem-orientated subject, which challenges lecturers to implement hands-on and cross-curricular approaches to teaching (Ankiewicz, 2018; Granshaw, 2010). Mechanical Technology (MT) is one of

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[4] In this study hPBL was used and structured around the development of projects

the main study fields within the Technology curriculum in the FET (Further Education and Training) phase (see Figure 1.1). Other examples of main study fields within the Technology curriculum are Electrical Technology and Civil Technology (see Figure 4.1).

Mechanical Technology focuses on concepts and principles in the mechanical environment, technological processes, practical skills and the application of scientific principles (DBE, 2014c). MT aims at the creation and improvement of the engineering and manufacturing environments to enhance life quality of individuals as well as society, and safeguard the sustainable use of the natural environment and resources (DBE, 2014c). In particular, MT covers topics in the mechanical field such as safety, tools, equipment, materials, terminology, maintenance, control systems, forces, mechanical systems, hydraulic systems, pneumatic systems, electrical systems, engines and drive trains (DBE, 2014c).

Embedded in MT are three clearly distinguishable disciplines: Automotive (MTA), Fitting and Machining, as well as Welding and Metalwork (DBE, 2014c) (see Figure 1.1). MT also involves the application of knowledge and skills with regard to evaluating, diagnosing, adjusting, removing, replacing, designing, maintaining, manufacturing, and communication of mechanical systems and components (DBE, 2014c).

This study focuses on MT with special attention to the Automotive discipline (MTA). In the Automotive discipline, students are equipped with skills allowing them to understand the design, development, manufacturing, repair, and maintenance of motor vehicles, motorcycles, mopeds, etc. (DBE, 2014c).

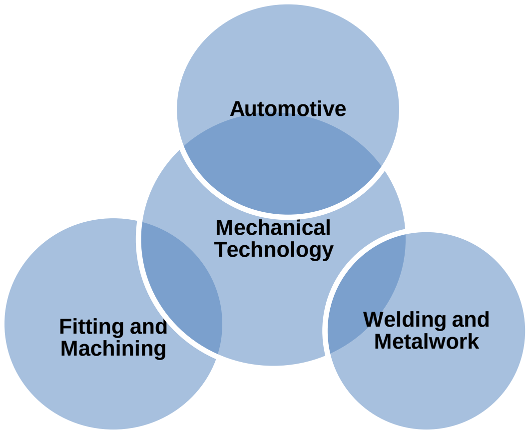

Figure 1:1: Mechanical Technology subjects in South Africa

Source: Compiled by researcher

1.4.4 Mechanical Technology for pre-service teachers

According to the programme outcomes (see Addendum N) for the Mechanical Technology BEd degree, these are aimed at preparing pre-service teachers to teach MT from grades 10 to 12 at various schools of technology[5] in South Africa (NWU, 2018). Mechanical Technology, with regard to the Automotive field, aims to: encompass theoretical and practical knowledge and skills with regard to petrol- and diesel-propelled vehicles, motorcycles, lawnmowers, generators, and tractor mechanics regarding components, systems, accessories, safety, dynamics, layout, and control. These include various practical competencies such as applying safety measures and using tools and equipment. The BEd programme also provides for the development of various didactical, professional, ethical, communicational, technological, practical and numerical competencies and responsibilities of future teachers (Benade, 2016; NWU, 2018).

A student who meets the entry requirements of the university (see Addendum N) can apply to enrol in the Technology Education programme (BEd) for the Further Education and Training (FET) phase to become a “technology” teacher. Before a student can focus on becoming an MT specialist or a Technology specialist, all first-year Technology students need to complete, over a period of two semesters, four technology modules covering electrical, civil and mechanical topics, as well as engineering graphics and

5 Although schools and communities still use the term ‘technical schools’, the correct term is ‘schools of technology’.

design as compulsory subjects. Exposure to the four technology areas allows the student to make an informed decision with regard to becoming an electrical, civil or mechanical technology teacher. MT topics covered in the modules Mechanical Technology for First Year Education Students (FETM 111 and FETM 121) are:

- hand and precision tools for use in the engineering industry;
- forces, moments and tension in materials;
- manufacturing and uses of iron and steel as engineering material;
- joining methods;
- mechanisms, systems and control;
- pneumatics and hydraulics;
- Curriculum and Assessment Policy Statement (CAPS) for General Education and Training (GET) phase; and
- Curriculum and Assessment Policy Statement (CAPS) for Further Education and Training (FET) phase;

From the second year onwards, prospective MT students focus on the three main areas in MT, namely Automotive, Fitting and Machining, and Welding (see Section 4.5 to 4.8 and Figure 1.1).

The quality education of pre-service MT teachers is important, because within the next few years, these candidate teachers will be in the frontline of teaching the "future" engineers, artisans, technicians, teachers, etc. Therefore, implementing hPBL in MT classes at university level may have a positive outcome with regard to the development of independent and responsible self-directed students.

1.5 Empirical research

This section outlines the research paradigm, methodology, design and methods, as well as the role of the researcher.

1.5.1 Research paradigm and methodology

The philosophical point of departure in this study was pragmatism. In this regard, James and Thayer (1975:2) once said, "all realities influence our practice", and Sharma *et al.* (2018:1549) said it is "a practical, matter-of-fact way of approaching or assessing situations or solving problems". Pragmatism can also be seen as "modern science-based upon experimental method" (Sharma *et al.,* 2018:1550). This, in short, describes the process behind pragmatist reasoning. Pragmatic research was selected, as the approach is based on the following principles (Camp, 2017):

- Emphasis on never-ending change. The fact that reality or truth is always changing and evolving.
- Emphasis on social aspects. Humans develop in social circumstances such as group work or teamwork.
- Experimentalism. All pragmatists are in reality experimentalists, and experimenting results in activity.

A pragmatist research approach allows the mixing of research results, as Bean (2011:14) puts it, "a bolts and nuts" approach. The researcher mixed and combined qualitative and quantitative research methods into a single (QUALquan) study (Creswell & Creswell, 2017; Miles, *et al.,* 2014. Onwuegbuzie *et al.*, 2009; Yilmaz, 2013.). Van der Walt and Potgieter (2012:222) describe the pragmatic research approach as an "experience-oriented, thoughtful dialectical method to solve individual and social problems". The researcher concurred with the above views that this was the best way to conduct the research.

A mixed methodology was used in this study (see Figure 1.2), as mixed methods provide various ways to answer the research question and it is a useful research methodology for conducting research that involves both qualitative and quantitative methods (Creswell, 2009). The rationale was that both quantitative and qualitative methods, in combination, provide a better understanding of research than a research approach on their own (Creswell, 2009; Maree, 2010; Miles, *et al.,* 2014). In this study, qualitative research carried greater weight (part of problem-based learning and project development) than quantitative research. Although Creswell (2009) mentions various mixed-method designs in this study, a general mixed-method approach was followed.

Design-based research (DBR) focuses on research where context-based methods are used to design and develop useful products such as artefacts (Havenga & Van Wyk, 2017). DBR focuses on *design experiments,* with the aim to bridge theory and practice in complex and challenging situations (Van Wyk & De Villiers, 2014). DBR is thus an appropriate approach for instructional[6] interventions to fill the gap between theory and practice, make provision to create artefacts to solve real-world problems, and develop theory or design principles (Van Wyk & De Villiers, 2014) (see Figure 1.3).

In this study, two cycles of DBR were executed during 2017 and 2018 (see Figure 1.2). In both cycles, one auto-electrical and one mechanical project were involved. The projects in 2018 were similar (but different in degree of difficulty) to the projects in 2017. However, they were placed on a higher level with regard to knowledge and skills, as both these ‘2018’ projects required in-depth research and advanced practical skills (see Table 5.8 and Section 5.5.5).

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6 Sometimes the term ‘instruction’ is used as an alternative for teaching and learning and education.

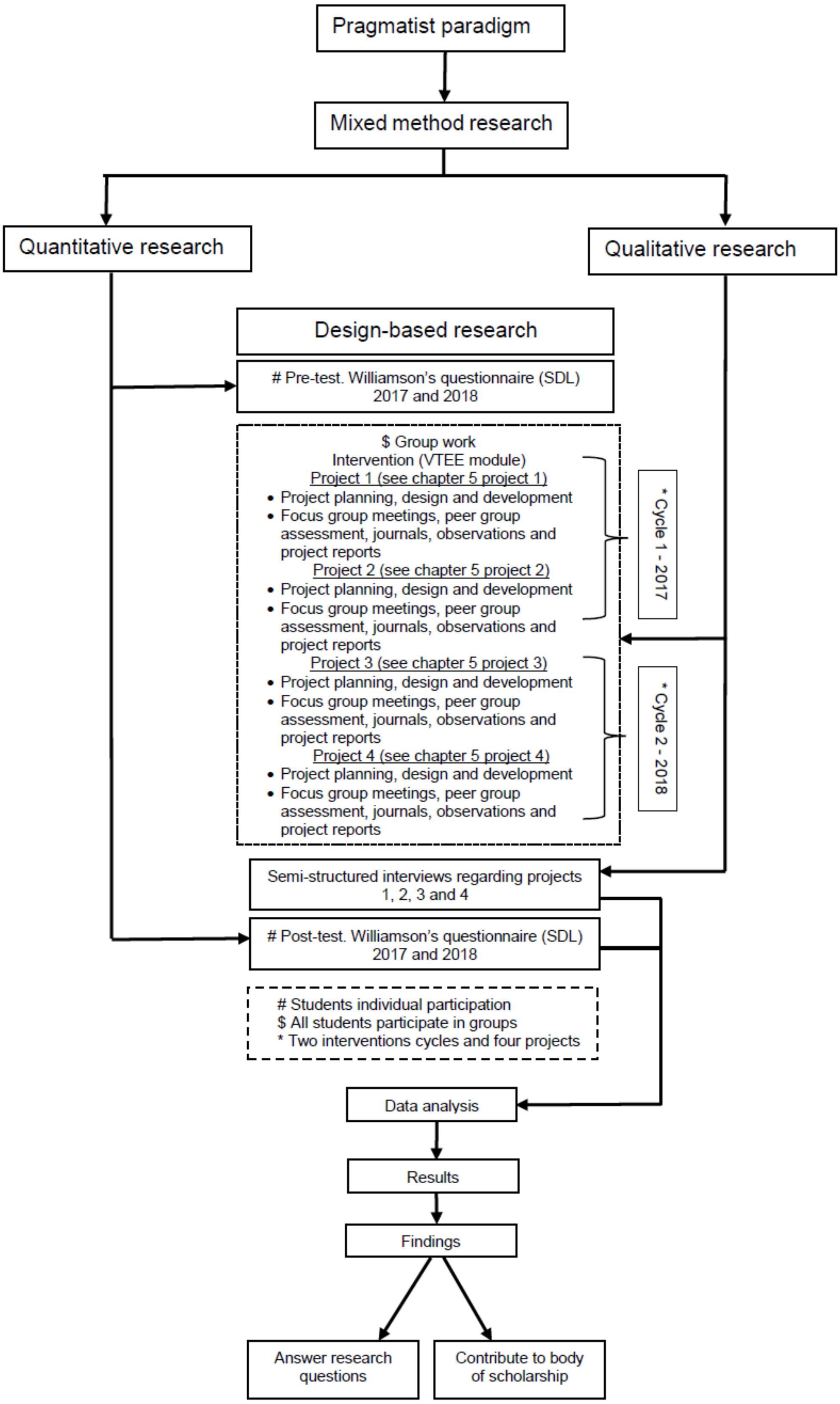

Figure 1:2: Research paradigm and methodology in this study

Source: Compiled by researcher

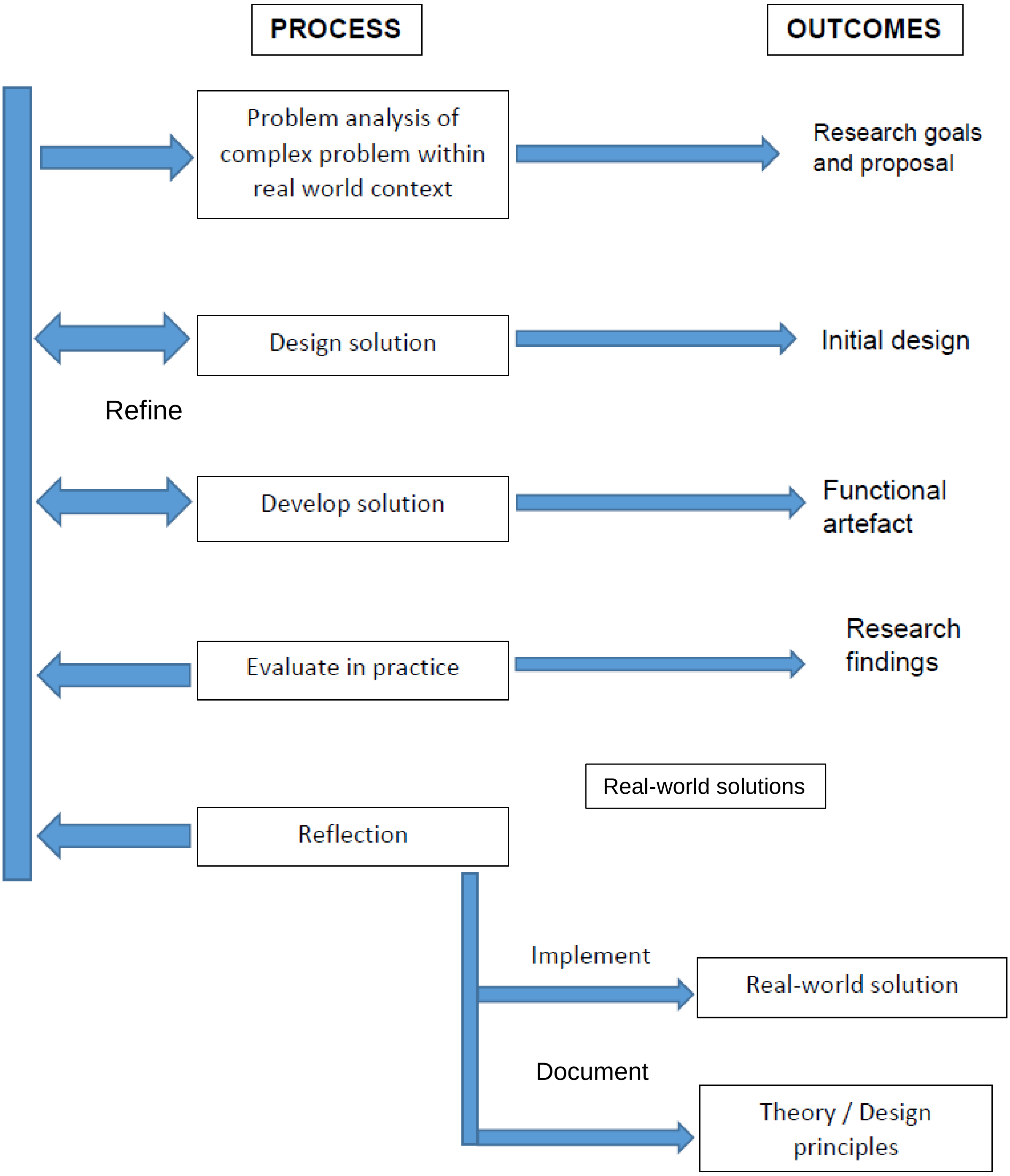

Figure 1:3: A synthesised generic model for design-based research (DBR)
Source: Van Wyk and De Villiers (2014:18)

Figure 1.3 is an adapted DBR model with the following phases: problem analysis within real world setting, design solution, develop solution, evaluate in practice, and reflection, leading to dual outcomes namely real world solutions and application of theory and design principles (Van Wyk & De Villiers, 2014). In this model, the outcomes are specified and the interactive nature of all actions is indicated. Moreover, problem-solving provides for developing group learning objectives and skills development, such as analysis, hypothesis generation, decision-making, problem-solving and evaluation (Van Wyk & De Villiers, 2014). Facilitation is crucial in PBL in the sense to direct students in their learning processes. A critical attribute of PBL is to ensure ownership on the part of students since they need to be engaged and intrinsically motivated to solve authentic problems (Van Wyk & De Viliers 2014).

In this study the application of DBR as well as the two cycles of research, is discussed in more detail in Chapter 5.

1.5.2 Selection of research site and population

The research was conducted on the Potchefstroom campus of the NWU. Participants were 2nd-year students enrolled in the BEd Mechanical Technology module (VTEE 222) in 2017 (N = 12), and the same students (less two) again in their 3rd-year module (VTEE 312) in 2018 (N = 10). The mentioned students participated, since the NWU is the only institution that offers BEd MT in South Africa. In 2017, participants were randomly selected as part of a group to assure that each individual had the same chance of being selected for a specific group. However, in 2018, students had the opportunity to select their own partners for teamwork for each project. As enrolments for 2018 changed, the group size had to be altered. For the semi-structured interviews, seven participants (four in 2017 and three in 2018) were randomly selected. (All participants had an equal chance of being selected.)

1.5.3 Data collection and the self-directed learning instrument

Quantitative data were obtained by using the Williamson questionnaire for self-directed learning (SRSSDL) as pre-test and post-test in 2017 and 2018 in both DBR cycles (Figure 1.2) (Williamson, 2007)(see 6.3).

Every second week during the interventions in 2017 and 2018 qualitative data were collected as follows (see Figure 1.2):

- focus-group interviews;

- project reports and journals;
- semi-structured individual interviews; and
- researcher observations.

To capture the essence of all the data emerging from the focus group interviews and individual semi-structured interviews fully, a recording device was used and recordings were transcribed verbatim. Photos were taken during the project development and students were requested to write two-weekly reports (see Chapter 6). Each participant was requested to keep a portfolio of his or her experiences during project design and development. In addition, participants were required to compile a portfolio of evidence containing drawings, calculations and relevant documents involved in the design and development of each project. The lecturer kept notes of activities.

1.5.4 Data analysis

Quantitative results (Williamson, 2007) were analysed by the researcher with the help of the Statistical Consultation Services of the university where the study was conducted. Statistical analysis involved descriptive statistics only (see Chapter 6).

The qualitative data were transcribed, analysed and categorised by the researcher using the ATLAS.ti™ software program (a computer-based qualitative analysis tool). The data of the group meetings were condensed into two sets (one set of notes for each project in each cycle) (see Figures 6.15 and 6.16). The individual semi-structured and focus group interviews were transcribed verbatim, the project reports/sheets and minutes of group meetings were condensed into one set of data (see section 6.7).

1.5.5 The role of the researcher

In this study, the researcher was facilitator, instructor and mentor all at the same time. This implied that the researcher needed to carefully plan all workshop-related concerns such as collecting, organising and handling components, applying safety measures, planning focus-group discussions, providing guidance with regard to skills development and techniques as well as record-keeping.

1.6 Ethical aspects

Approval (see addendum Q) was obtained from the Faculty of Education Research Ethics Committee (EduREC). Once ethical approval was granted (NWU-00484-17-A2*)*, the proposal application was sent to the Institutional Registrar to grant permission for students to participate. Respondents participated voluntarily, and although they reserved the right to withdraw from completion of the questionnaires and participation of interviews, participating in project development was compulsory as part of both VTEE courses. All participants initially completed informed consent.

1.7 Contribution of this study

As the Faculty of Education where the research was conducted has an SDL Research Unit, the proposed research contributed to the body of scientific knowledge and scholarship pertaining to the Research Unit of SDL (see Chapter 7).

This study also offered a deeper understanding of applying PBL teaching–learning strategy in subjects with a practical component. This provides a guide for implementing hPBL in MT practical sessions for pre-service teacher-student preparation at a tertiary institution. The findings may also assist Technology lecturers and curriculum developers with regard to the application of PBL to enhance students' self-directed learning abilities. This study aims to contribute to the development of a model for future teacher education in MT with regard to enhancing students' SDL (see Chapter 7).

1.8 Structure of this thesis

The structure of the thesis is as follows

Chapter 1: Theoretical background and problem statement

Chapter 2: Problem-based learning: A theoretical overview

Chapter 3: Self-directed learning: A requirement for Mechanical Technology education

Chapter 4: Mechanical Technology: Overview and development of essential knowledge and skills

Chapter 5: Research design and methodology

Chapter 6: Data analyses and research results

Chapter 7: Conclusion and recommendations

CHAPTER 2: PROBLEM-BASED LEARNING: A THEORETICAL OVERVIEW

2.1 Introduction

This chapter focuses on the outlining of teaching, learning, related theories and various aspects of problem-based learning (PBL).

Teaching is the practice of specific and intentional involvement in assisting people to learn particular things with regard to their needs, experiences, existing knowledge and feelings (Wlodkowski & Ginsberg, 2017). Teaching can be seen as a process wherein individuals interact with their learning environment, the content, as well as with one another (Hurst *et al.*, 2013; Jones, 2011). Teaching involves the interpersonal and dynamic relationship between educators and students or learners originating from deliberate acts of communication and other activities, aimed at changing students' long-term behaviour, knowledge, attitudes and skills (Jennings & Greenberg, 2009). In teaching, educators offer the underpinning for knowledge acquisition and encourage students to develop and use higher-order thinking skills to understand the facts and assess new knowledge (Jones, 2011; Savery, 2015).

According to Kolb (2014), learning is an activity whereby knowledge is formed through the conversion of experiences. Scholars define learning as an active social discovery process guided by a teacher, or creation of knowledge structures from personal experiences (Bonawitz *et al.*, 2009; Snowman *et al.*, 2011). Learning is an active cognitive process arising from ideas and constructed by means of discussion (Bean, 2011). Although many definitions regarding learning could be found, all agree that learning is created by an active personal interpretation of experiences, and that it builds on the relation between new and existing concepts.

Active learning results from students engaging in meaningful learning activities and reflecting on what they are doing, while on the other hand, passive learning is where students passively receive information from the educator by means of more traditional lecturing (Biggs & Tang, 2011; Dabbagh & Kitsantas, 2012; Kumpulainen *et al.*, 2009). One example of an active learning approach is problem-based learning (PBL). One feature of PBL, among others, is that students work together in small groups to enhance the learning process (Johnson & Johnson, 2009; Li & Lam, 2013). Although there are various ways for applying PBL, they all emphasise a student-centred strategy in support of active learning where students are faced with a problem of inquiry and the problem serves as the context as well as the motivation for the learning that may follow (McLoughlin & Lee, 2010). Thus, PBL requires active participation and is mainly cooperative by nature (Belland, 2014; Biggs & Tang, 2011).

2.2 Theoretical perspectives of problem-based learning

Learning theories are descriptive by nature, as they outline the process of learning by making statements about how people learn and how they should learn (Snowman *et al.,* 2011). In education, learning theories play a major role with regard to the selection of appropriate models and the acquisition of knowledge (Metzler, 2017). According to Servant (2016), the main paradigm for understanding the problem-based learning context is constructivism, and therefore this will be discussed briefly.

2.2.1 Constructivist learning theory

Constructivism is a theory describing learning as a result of a cognitive process where individuals gain knowledge by actively organising information and enhancing understanding of topics rather than having understanding transferred to them by some other means (Burr, 2015; Piaget & Cook, 1952).

As confirmed by Li and Lam (2013) and Kolb (2014), the use of constructivist teaching and learning approaches is not new. In 1995, Phillips identified three types of constructivist *learning* that he called active learning, social learning and creative learning (Phillips, 1995). This was confirmed by Wals (2010) and Williamson (2013) who elaborated by defining three types of *learners*, namely *active* learners, *social* learners and *creative* learners. Active learners will acquire knowledge and understanding in a dynamic way by means of activities such as discussion, debate, hypotheses and investigation. Social learners tend to acquire knowledge and understanding by means of social interaction and dialogue with others. Creative learners acquire knowledge and understanding by means of a creative process, using previous knowledge and understanding to develop and gain new knowledge and understanding by combining the previous two learning processes in a more complex mix of social activities and experiences (Burr, 2015; Kolb, 2014).

A recent theory based on constructivism is social constructivism. Lev Vygotsky, a Russian psychologist, developed a subdivision of cognitive psychology, which soon became known as ‘constructivist psychology’ (Martin & Bickhard, 2013). Vygotsky’s main concept of thinking focuses on the Zone of Proximal Development (ZPD) (Arends, 2014). The ZPD refers to “any situation in which, while participating in an activity, individuals are in the process of developing mastery of practice or understanding of a topic” (Arends, 2014:14). Social constructivists believe that learning is a process whereby reality and knowledge are constructed by social interaction through human activity by different members of society (Kiraly, 2014). Active learning is, therefore, a social non-passive process whereby behaviour is shaped in individuals and members of groups by external and internal feedback or by any other “instructional activities involving students in doing things and thinking about what they are doing” (Brame, 2016:1; Carr *et al.*, 2015).

There are some similarities between constructivist thinking and PBL, since both emphasise that learning develops through interaction where students need to engage with the topic and learning environment. PBL and social constructivist thinking are for example both supporters of, amongst others, the use of small groups as a unit of learning with accompanying reduction of lectures (Loyens *et al.*, 2010; Servant, 2016). This is confirmed by Creswell and Creswell (2017) who define social constructivism as a process of forming subjective meanings of experiences when individuals work together.

2.2.2 Historical view of PBL

Before PBL can be defined, it is relevant to look at the run-up with regard to the underlying theory and intellectual thinking that played a role in PBL development. Figure 2.1 outlines the various intellectual influences with regard to PBL, which resulted in the use of the Maastricht and Aalborg models, amongst others. From the historical tree of the development of PBL in Figure. 2.1, it can be observed that some of the models influenced one another as they share the thinking of several scholars (Servant, 2016). The Maastricht model of PBL was affected by constructivist psychology, Roskilde by Marxist philosophy and McMasters and Aalborg by a comprehensive range of inspirations ranging from humanist psychology to educational philosophy. The influence of Marxist philosophy was limited to the Aalborg PBL model, the Danish Council for Strategic Research (DSF) and Roskilde models, and did not emerge in the medical PBL models (Servant, 2016). Through the work of Illeris, the Aalborg model shared contributions of Dewey and Rogers that were also present at McMasters, and the Piagetian impact that was present at Maastricht. According to Servant (2016), the influence of Dewey and Piaget was the greatest.

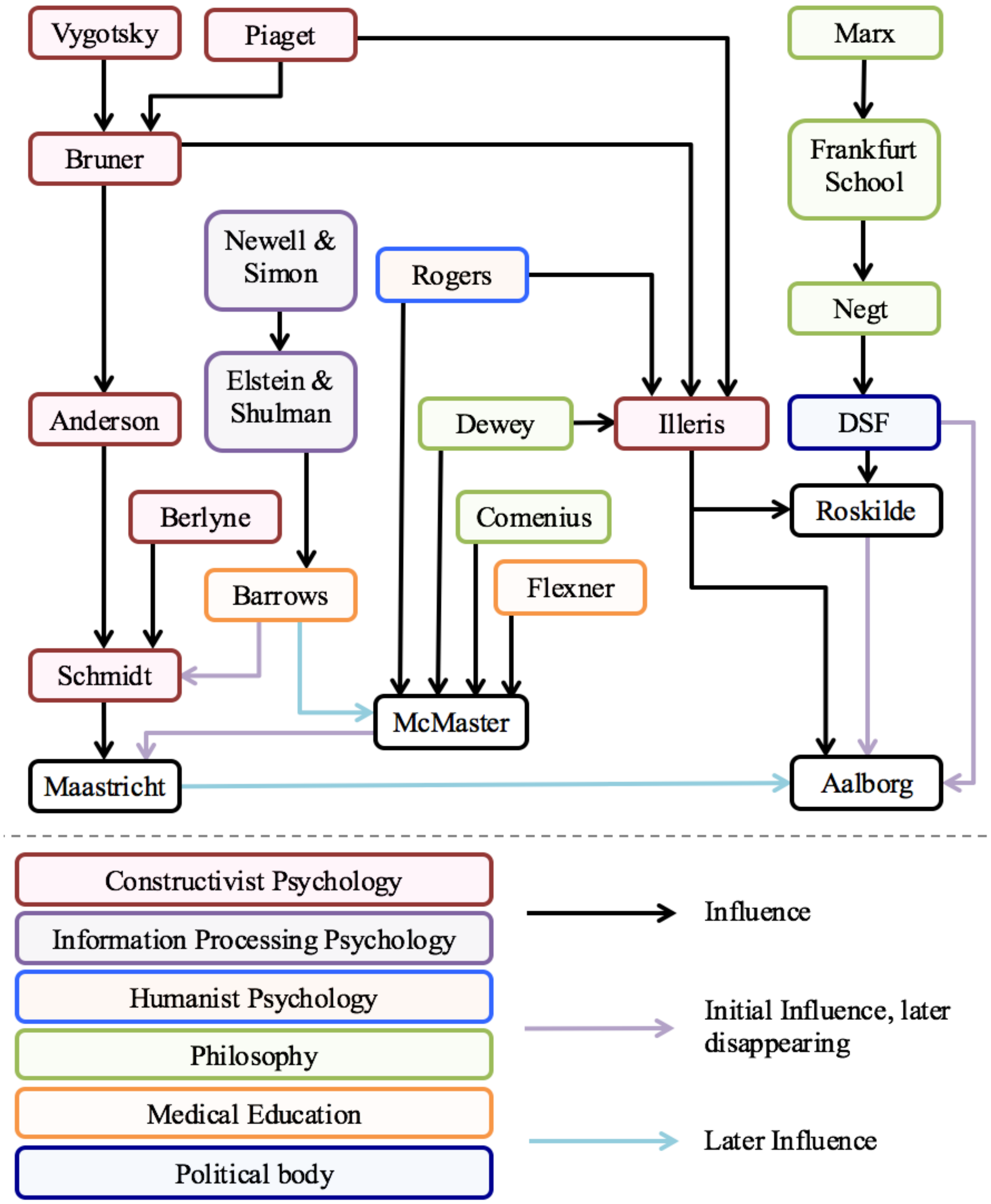

Figure 2:1: Historical Tree of Intellectual Influences in Problem-Oriented Education

Source: Servant (2016:239)

2.3 Problem-based learning

Barrows and Tamblyn (1980:18) originally defined PBL as –

> *[T]he learning that results from the process of working toward the understanding or resolution of a problem. The problem is encountered first in the learning process and serves as a focus or stimulus for the application of problem-solving or reasoning skills, as well as for the search for, or study of, information or knowledge needed to understand the mechanisms responsible for the problem and how it might be resolved.*

PBL is basically a discovery learning experience where students work in small groups under the guidance of an implementer in order to solve a challenging problem (Kwan, 2009; Yilmaz, 2011). PBL also allows students to develop scientific skills such as gathering information and transferring the gained knowledge and experiences to related real-world tasks (Diemer, 2014; Fotis, 2016). Furthermore, PBL is an instructional, student-centred strategy that can be applied in learning environments where problems are used to offer the content for covering learning goals (So & Kim, 2009). Educational and psychological theories (see Section 2.2) provided a foundation for the practice and organisation of PBL in terms of mixing practical and theoretical work into one unified learning experience (So & Kim, 2009; Walker *et al.*, 2015). In PBL, students should reflect on what they have learned with regard to their contribution and those of their peers (Savery, 2015; Walker *et al.*, 2015). Although PBL addresses real-world problems, it does not focus on problem-solving as such, but rather on developing knowledge and various skills as a result of problem-based experiences (Jonassen & Hung, 2015).

According to Pecore (2013), PBL aligns with the constructivist theory in that it promotes learner or student engagement in the construction of knowledge that is relevant and supported by peers. PBL aims to allow students making sense of their knowledge as they try to solve authentic problems from given programme content (Beaumont, 2015; Çaliskan, 2013). PBL promotes lifelong learning through the process of investigation and collaboration and is reinforced by academic scaffolding (Keebaugh *et al.*, 2009; Kim & Hannafin, 2011).

The widespread use of PBL sometimes leads to incorrect use thereof resulting from confusing PBL with problem-solving (Huijser & Kek, 2016; Walker *et al.*, 2015). The main difference between PBL and problem-solving can be explained as follows, according to Neville (2009:2). PBL (in medical education) has four major objectives, namely "structuring of knowledge and clinical context, clinical reasoning, self-directed learning skills and intrinsic motivation" while problem-solving only has one objective and that is to solve a problem. Another difference is that problem-solving usually relies on trial and error or a step by step process while PBL relies more on finding a solution to an ill-defined problem by means of various carefully-selected steps (Greiff *et al.*, 2014; Walker & Leary, 2009).

2.3.1 The origin of problem-based learning

Finding an exact date where and when PBL started is not possible, but one can find many individuals who contributed to the development of PBL as we know it today. According to Boss (2011), Confucius, Socrates, and Aristotle were some of the first advocates of learning by means of doing and through questioning, inquiry, and critical thinking - ideas that are still very relevant in PBL classrooms. Another contributor was John Dewey, a 20^{th}-century American educational philosopher who advocated learning that is grounded in practice and driven by student interest (Roberts, 2011).

According to Servant (2016) and others such as Schmidt *et al.* (2011), PBL (as we know it today) has been about for more than 45 years. PBL became one of the preferable teaching and learning strategies at McMaster University in Canada (Greenlee, 2015). Although PBL was implemented in the medical and health sciences education at McMaster University, it soon emerged as an effective approach in engineering, law, psychology, social sciences, arts and humanity education across the world (Conrad & Dunek, 2012; Nilson, 2016). Other researchers argued that PBL rather originated from the Aalborg PBL model that can be linked to the Danish model of 'problem-orientation' introduced in 1972 in Roskilde and the project-based model of scholars such as Morgan and Blumenfield (see Figure 2.1) (Kolmos & De Graaff, 2007; Servant, 2016).

In Table 2.1, the researcher integrated the main contributors and run-up to the implementation and use of PBL as we know it today.

Table 2:1: Five important contributors to modern problem-based learning
Source: Compiled by the researcher

Year and domicile of implementation	Contribution	People involved
1966. The Faculty of Medicine at McMaster University in Canada	Although some evidence to the use of PBL can be traced back as far as 1910, it found momentum in 1966. Originally intended for the preparation of medical practitioners, it soon led to the widespread use of PBL in many universities across the world.	Howard Barrows, Abraham Flexner, Bill Spaulding, Jim Anderson and John Evans (De Graaff & Kolmos, 2007; Hamilton, 2005; Hillen *et al.*, 2010).
1972. The University of Limburg at Maastricht in the Netherlands	Scholars pioneering work in using PBL curriculum in medical schools had the result that some universities in the Netherlands are now using some PBL elements in their medical curriculum.	Harmen Tiddens and Wynand Wijnen (Hillen *et al.*, 2010).
1974. The University of Aalborg in Denmark	Aalborg offered a clarification of the use of problems in education by defying traditional authority and improving engineering education. In fact, the UNESCO chair for PBL is located at Aalborg University in Denmark.	Mona Dahms, Stig Enemark, Anette Kolmos and Lone Krogh (Servant, 2016).
1978. The University of Newcastle in Australia	Started PBL in medical education in Australia, at first not very successful but later paved the way for PBL in all medical schools, engineering and other disciplines in Australia.	Jim Anderson and John Hamilton (Finucane & Nair, 2002; Hamilton, 2005; Li & Henriksen, 2010).
1979. The University of New Mexico in the United States	Scholars found that the motivational features of PBL outweigh the negative features and that medical students following the PBL programme become skilled in a comprehensive style of learning.	Bob Waterman, Arthur Kaufman, Stewart Mennin, Scott Obenshain, Marty Kantrowitz, Becky Jackson, Stuart Duban, Max Bennett, Dayton Vorhees, and Bill Galey (Richter, 2012).

2.3.2 The problem in problem-based learning

Figure 2.2 displays the *problem* aspect of PBL with regard to SDL, as the *problem* is a crucial part of designing a PBL experience and it is central to the understanding of the PBL approach (Savery, 2015). Recent research established that the importance of the problem should carry more weight than the complexity of the problem (Walker *et al.*, 2015). In other words, students should learn how to approach a problem of inquiry (Hung & Loyens, 2012; Savery, 2015; Walker *et al.*, 2015). Although most researchers agree that the problem in PBL is very important, there seem to be several *aspects* with regard to the problem that should be considered before introducing students to PBL. According to Hung *et al.* (2008) and Jonassen (2010), these aspects are the level, complexity, structuredness, relevance and the type of problem students are confronted with. The *level* of the 'problem' refers to matching the problem with the learning phase and the probability of solving it (see Table 2.2), the *complexity* reflects on the difficulty of the problem and the *structuredness* is how well- or ill-structured the problem is (Jonassen, 2010; Sockalingam *et al.*, 2011). Examples of well-structured problems are algorithmic problems, word problems and rule application problems, while troubleshooting problems and diagnostic problems are considered less well-structured problems, and problems like dilemmas, scenario's and designs are seen as good examples of ill-structured problems (Hung *et al.*, 2008; Jonassen, 2011). Therefore, using problems of the latter type will be ideal for PBL. Ill-structured problems have ill-defined goals. They have various solution pathways and should have no obvious simple resolution (Jonassen, 2010). Ill-structured problems should involve several evaluation options and should encourage students to make their own decisions (Van Merriënboer & Kirschner, 2017). The *relevance and the type* of problem refers to how well the problem fits into the curriculum (see Table 4.3 and section 4.5.3) and how applicable the problem is to the situation (Azer, 2009; Reid, 2013).

The problem level refers to the difficulty of the problem and it is worth noting that, although the level of difficulty is relevant, it does not play a major role in the PBL implementation (Walker & Leary, 2009). The level of difficulty should serve as an indication of the probability of solving the problem rather than serving as a major contributing factor to the successful introduction to PBL (Walker *et al.*, 2015). The complexity of the problem may sound similar to the difficulty of the problem, but it is in fact rather a reference to the extent or magnitude of the problem, which in turn refers to the amount of knowledge and not the level of knowledge the problem solver needs in order to solve it. In other words, the problem in PBL should be appropriate and relevant to the situation in which it is used (Eraut, 2012; Hung, 2006; Savery, 2015). This implies that, when selecting an appropriate problem, it should have multiple possibilities in solving it and not a problem with an obvious solution (Biggs, 2011; Walker & Leary, 2009).

Another view is that PBL is a *minimal guidance instruction method* where students are challenged to solve authentic problems in an information-rich setting (Kirschner *et al.* 2006). He emphasises that such a PBL approach is likely to be ineffective in supporting cognitive processing necessary for learning. According to Sweller (2012), human cognitive development refers to the manner in which cognitive structures such as working memory and long-term memory are organised to process information and this is where PBL falls short. Although there are different views on PBL, the author is of the opinion that traditional teacher-centred instruction such as direct lectures that focus mainly on passive learning is not effective during practical work. This is supported by Frambach *et al*. (2012), stating that traditional teaching methods do not necessarily support independent and self-directed learning. This highlights a gap between what students learn in university and what they need to do in practice after graduation. The author concurs with Bagheri *et al*. (2013) who focuses on introducing problem-based learning (PBL) as an initiative to bridge the gap between theory and practice (see Section 2.5).

Although this study does not focus on the education of engineers, the education of MT students is in many ways similar in terms of applying various teaching-learning strategies to solve real-world problems. In order to solve workplace problems, students should develop ample theoretical knowledge and have ample time to apply the knowledge in resolving complex, ill-structured problems (Jonassen, 2010; Ramirez *et al.*, 2012).

The unpredictability of an appropriate problem for PBL sometimes inspires further learning from both the students and lecturers as it necessitates research, expansion, further study and fusion together with choices and action (Mitchell-White, 2010).

2.3.3 Characteristics of problem-based learning

The main characteristics of PBL are discussed briefly. PBL comprises students taking responsibility for their own tasks, empowered to conduct research, working in small groups and addressing ill-structured problems (English, 2013). PBL is a student-centred teaching and learning approach where theory and practice are integrated, knowledge and skills are applied, feasible solutions to distinct problems are developed, and self-directedness and motivation are promoted (Savery, 2015; Walker *et al.*, 2015). Furthermore, PBL motivates and encourages students to take ownership of learning and engage with the problem within the limits of existing skills and understanding (English & Kitsantas, 2013; Wang *et al.*, 2017).

The role of cooperation and teamwork is also important when applying PBL, as it closely resembles real-world settings where students need to share responsibility and liability with regard to the problem (Michaelsen *et al.*, 2014). Prior knowledge and understanding should be reapplied to the problem as this allows individuals to share knowledge, skills and experience to enhance group performance (Hung, 2011; Hung *et al.*, 2008; Lew & Schmidt, 2011; Savery, 2015).

In addition, PBL is also characterised by the use of reflection, since it helps to monitor and consolidate the learning that developed during the PBL task or project, and serves as reinforcement for refining metacognitive thinking (Boud *et al.*, 2013; Scardamalia *et al.*, 2012). Evaluation of the final PBL project or task should include the assessment of the evolvement of each individual team member throughout the development process, as this can provide valuable information regarding the process development as well as the knowledge and skills obtained during the PBL project (Bellström & Kilbrink, 2009; Darling-Hammond *et al.*, 2015). In addition, the challenge of solving a problem requires students to take the initiative and direct their own learning processes (Lazakidou & Retalis, 2010).

An essential characteristic of PBL is the key role of the facilitator who assists in the development of problem-solving and high-order thinking skills, instead of using more traditional teaching methods such as lecturing (Botha, 2012; Wang *et al.*, 2017; Wang & Cranton, 2012). In order to keep students motivated and focused in classrooms, educators should keep in mind that finding a solution to a problem should not be too obvious (ill-defined), *but* it should incorporate a variety of subject disciplines and integrate a wide range of information and skills (Savery, 2015; So & Kim, 2009). Another characteristic of PBL is the use of tutors. A tutor is an additional person such as a senior student in the class (there can be more than one) who assists students and guide the problem-solving process (Turan *et al.*, 2009). The role of a tutor is important as he or she can, in addition, probe questions to help students focus on the problem, encourage students to use academic terms, plan ventures regarding the project, and encourage students to participate (Donnelly, 2013; Turan *et al.*, 2009).

2.3.4 Problem-based learning in South Africa

Finding the exact dates and identifying individuals who first introduced PBL in South Africa is not an easy task, as more than one institution started using PBL at more or less the same time. Examples of these are: Prof Barbara Robertson who was appointed in April 1986 at the University of the Witwatersrand (WITS) as head of the Department of Nursing. She had an important role in establishing a PBL programme when she introduced PBL in nursing training in the 1990s. Also, the Science of Occupation and Occupational Therapy education at WITS implemented PBL in their programme in 1995 (Horwitz, 2011; Malan & Ndlovu, 2014).

Another example of the use of PBL in university curricula is, the Walter Sisulu University (WSU), former University of Transkei (Unitra), who implemented PBL in 1992 for medical training, and the Nelson Mandela School of Medicine (University of KwaZulu-Natal) who started using PBL in 2001 (Iputo, 2008; McLean *et al.*, 2006).

Currently, some South African universities offering Bachelor of Medicine and Bachelor of Surgery degrees (MBChB) are using the PBL approach for medical training. According to Kwizera *et al.* (2008:293), there is a “growing evidence that the pedagogical approach of PBL tends to improve academic performance assessed in terms of increasing throughput rates and reduced attrition rates”. The benefits of using PBL in curricula are confirmed by Nafees *et al.* (2012:166) who claim, “it is possible for students in a problem-based instructional strategy to perform better than the students in a conventional, lecture-based instructional strategy”.

In addition, Stenden (a private Higher Education Institution) in Port Alfred offers degree programmes in Disaster Management and Hospitality Management that are based on problem-based learning (Stenden, 2011).

2.4 Problem-based learning models

When implementing PBL as a teaching-learning activity, different approaches or models can be used depending on the particular context (Bishop & Verleger, 2013; Hung, 2011).

For example, the Mathematics educator can use a different approach in applying PBL than the History educator. It is essential that the activities performed during a PBL task should serve the purpose of simulating real-world problems in a controlled environment (Biggs, 2011).

Barrows, as referred to by Hung (2011), proposed a taxonomy that classifies PBL approaches into six categories (Figure 2.2), using two variables and three levels. The two variables are the degree of self-directedness (*y*-axis) and problem structuredness (x-axis). The three levels for the variable of self-directedness are instructor directed, partially self- or instructor directed, and self-directed, while the three levels for the variance of problem structuredness are well-structured, ill-structured and between well- and ill-structured (Hung, 2011).

Examples of different models of PBL (see Figure 2.2) can be identified as the *instructor-based with problem-solving activities model*, the *case-based learning model*, the *project-based learning model*, the *anchored instruction model*, the *hybrid-PBL model (hPBL)*, and the *pure PBL model* (Hung, 2011).

The PBL[7] model that has been used successfully for many years in engineering is hybrid-problem-based learning (hPBL) (Nielsen *et al.*, 2010). Briefly, hPBL is a model where a combination of focused instruction (mini-lectures) *and* project work are used (Wang *et al.*, 2017). It is, however, important to distinguish between pure PBL and hPBL. Pure PBL is according to Lee *et al.* (2010) and Neville (2009), *problem first learning* in that it is the *problem*, typically set by the facilitator, which outlines what needs to be learned (curriculum content) whereas course and assignment content in hPBL is organised around problem *scenarios.* The importance of 'hybrid' in PBL is 'the use of some form of traditional instruction (usually mini-lectures or demonstrations) in PBL (Azer, 2009). A mini-lecture is a short lecture or lesson of 10 to 15 minutes to provide an overview of a topic in an efficient way to save time and to improve understanding, or to link prior knowledge to a new topic (Smith & Waller, 1997; Kahn & O'Rourke, 2005; Millis, 2012). According to Baresh *et al.* (2018) and Salari *et al.* (2018), the main difference between PBL and hPBL lies in the duration of the problems and the inclusion of lectures. For example, with regard to the duration of an hPBL project, it all depends on how much time

[7] Although hPBL were implemented in this study the researcher sometimes refers to PBL.

is spent on actual PBL activities and how much on other activities, such as demonstrations and mini-lectures (Baresh *et al., 2018)*. In hPBL, mini-lectures are allowed to be used in conjunction with pure PBL (PPBL) activities (Malik & Malik, 2018).

Strobel and Van Barneveld (2009), Padmavathy and Mareesh (2013) and Walker *et al.* (2015) agreed that PBL (in general) can improve the student's capacity in problem generalisation, the classification and enhancement of the problem. Furthermore, PBL has the potential to modify the style of learning from *surface approach to learning* to a *deep approach to learning* (Samarakoon *et al.,* 2013; Golightly & Raath, 2015; Papinczak, 2009).

A deep approach[8] to learning is a "learning approach whereby students engage meaningfully with the subject matter and treat course content as something worthy of taking their time to get to know and understand" (Howie & Bagnall, 2013:391). According to Entwistel (2003), when students are engaged in a deep approach to learning, they intend to extract meaning, become active in learning and examine the content. It is also about significant engagement in tasks, focusing on basic values, main ideas, themes and principles, refining ideas, using evidence and applying that knowledge (Biggs & Tang, 2011; McCune & Entwistle, 2000). According to Biggs & Tang (2011:26) "…deep learning arises from the need to engage the task appropriately and meaningfully…". The importance of a deep approach to learning is that it may trigger the curiosity of a student, make him/her determined to do well in a specific task and allow him/her to focus on a high level of abstraction.

Surface approach to learning on the other hand is learning to memorise, store and reproduce information and *deep approach to learning* is learning to improve understanding of the content matter (O'Kelly, 2005). The advantages of a deep approach to learning are that students attempt to understand content, seek interaction with knowledge, relate learning to previous knowledge, integrate ideas, and question the logic of arguments (Lublin, 2003). This could be advantageous to foster SDL during the interventions in this study.

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[8] Some researchers use the term "deep approach to learning" and others use the term "deep learning".

Furthermore, PBL may enhance long-term retention of knowledge and skills, as Strobel and Van Barneveld (2009) and Whitmore (2010) found this approach to be effective when it comes to long-term remembering and learning routine.

The Aalborg PBL model and the Maastricht model are discussed in more detail since both these models make use of principles similar to the hPBL approach (Edström & Kolmos, 2014).

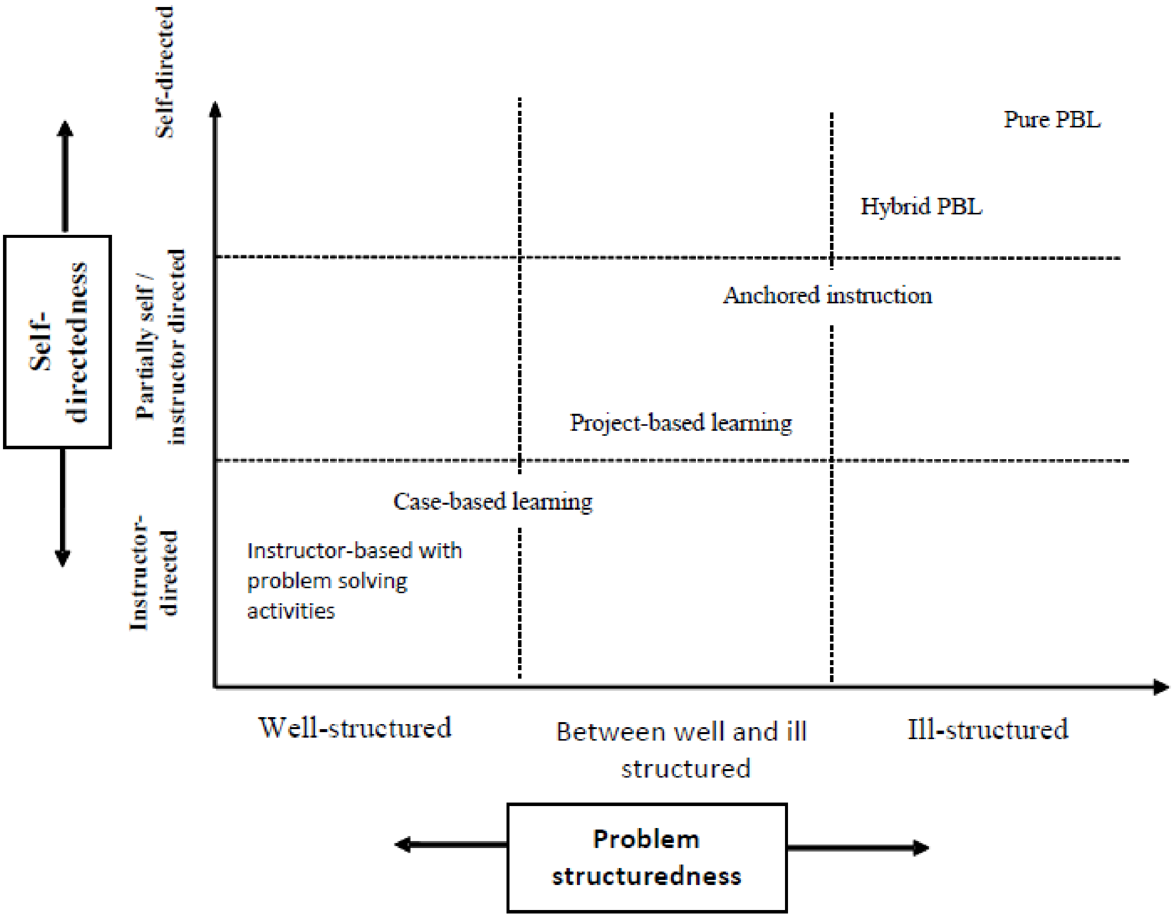

Figure 2:2: Six representative problem-based models in Barrows' taxonomy. Source: Hung (2011)

2.4.1 The Aalborg model

At the University of Aalborg in Denmark, PBL was introduced and used since 1974 in an effort to provide students with a dynamic participating role in the acquisition and creation of knowledge, skills, and understanding (Guerra & Kolmos, 2011). The Aalborg model (see Figure 2.3) can rightly be called *problem-based, project-organised learning* (Andersen, 2013; Krogh & Aarup Jensen, 2009). Researchers at Aalborg rethink the role of the teacher or lecturer in the learning process. In PBL, lecturers should act as learning agents, focusing on student activities and group work in order to promote the transfer and development of knowledge (Barge, 2010; Goodhew, 2010).

In practice, according to Kolmos *et al.* (2013) and Ulseth *et al.* (2011) the lecturer or teacher begins with the formulation of a real-world problem as the initial point of learning. Subject knowledge and prior knowledge are used to define the problem within the specific subject context. Students work in small groups to design, manage and complete a project to address the stated problem. When applying the Aalborg model, understanding of the 'basic assumptions' with regard to PBL is important (Sahin, 2010). These involve the *problem* (from any academic or technical field) as the starting point directing all learning activities, the *project development* guiding the learning by setting the context, and the *students* working in groups (see 2.3.1) (Barge, 2010). In the Aalborg PBL model some important elements should be present (Dann, 2013). These are:

- the problem as main focus;
- the project organised in groups;
- the course supporting the project;
- collaboration in group context;
- exemplarity with regard to appropriate learning material and content; and
- student responsibility in learning activities.

Together these variables or elements allow for the structuring of teaching and learning in a well-organised manner (Davies *et al.*, 2011). An hPBL project could for example also include similar elements with the addition of mini-lectures (Azer, 2009).

The Aalborg model is characterised by the use of exemplarity, teamwork and collaboration (Kolmos *et al.*, 2008). Exemplarity refers to the aspect of choosing appropriate learning material and content that complement the overall learning outcomes. In other words, the problem should refer back to a specific practical, technical-scientific or academic area (Barge, 2010; Dann, 2013; Viennot, 2010). Teamwork and cooperative learning involve individuals working on a project in small groups (3-5), cooperative team decisions and analyses, and team reflection on the project afterwards. Cooperation in a group allows for the development of team cohesion, which helps the members to complete the project or problem successfully (Barge, 2010; Prince, 2004).

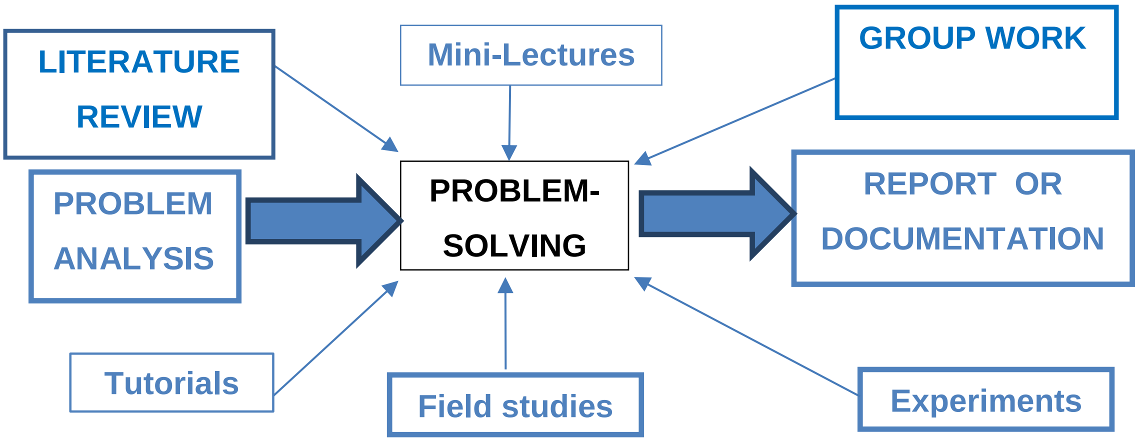

Figure 2:3: The Aalborg PBL model
Source: Kolmos *et al.* (2004).

2.4.2 The Maastricht model

The Maastricht model (comparable to the hPBL model) was developed at the University of Maastricht in 1972, where students are guided by the lecturer by means of mini-lectures, case studies, demonstrations, practical sessions and appropriate resources (Deignan, 2009; Kahn & O'Rourke, 2005; Smith, 2005).

When using projects in the Maastricht PBL model it is usually referred to as a project-based project (PBP) (Hanney & Savin-Baden, 2013; Throndahl *et al.,* 2018). Assessment of a PBP aims at quantifying the progress of knowledge and skills developed during the duration of the project. Many forms of formative and summative assessment such as tests, examinations, rubrics, portfolios, observations, reflections and interviews can be used (Bell, 2010). With regard to assessing PBL, students should know where they were, where they are and where they are going (with regard to learning activities), which can be achieved with regular reflection and by setting well-defined criteria at the start of the project (Gavin, 2011). Therefore, PBPs could be the vehicle driving the original goals of the project to gain knowledge and understanding through a self-directed, tutor-engaged learning experience (Bellström & Kilbrink, 2009; Masek & Yamin, 2010; Metzler & Shea, 2011).

The Maastricht PBL model usually involves seven steps and is therefore called the seven-jump approach (see Figure 2.4).

The seven steps of the Maastricht model are according to Bokonjic *et al.* (2009):

[1]. *The Clarifying terms*. At the beginning of the session, the problem(s) should be presented to students. The first activity of the group should thus be the clarification of problems, terms and concepts. The purpose of the first step is to agree on the meaning of the various words and terms and on the context described in the problem.

[2]. *Define* (concise) the problem(s) to be discussed. Defining the problem is the main goal during this phase. The group should discuss and reach an agreement on the challenging issues regarding the problem, which needs explanation. Though students may have some prior knowledge this may not be sufficient to resolve the problem as initially anticipated.

[3]. *Brainstorming*. Prior knowledge is recalled with the aim to structure the problem and consider possible solutions. Each individual may contribute his or her ideas about how to address the problem. The aim is mainly to collect as many ideas as possible.

[4]. *Categorise and structure* ideas. Review previous steps and provide tentative solutions. The problem should be explained in different ways and contributing ideas should be discussed. Team members and the tutor could probe additional views and reflect on them. The process of brainstorming and discussion is a collaborative initiative that results in generating various creative ideas.

[5]. *Identify and formulate* learning objectives. The team should reach consensus regarding the learning objectives and the tutor/instructor should ensure that the learning objectives are suitable, focused, achievable and complete. The objectives should be written down and may suggest possible learning outcomes. As student's prior knowledge are limited, questions, dilemmas and some conflict can arise and may encourage students to discuss these in more detail. This is called *cognitive conflict*

between what one knows and what one needs to know. The main aim is to formulate learning objectives to be addressed in the following steps.

[6]. *Search for information.* This step is to search for information and students use the internet or related resources. Students should provide answers to the questions induced in the problem-analysis steps and offer possible insightful knowledge and processes at the root of the problem. Group members gather information individually or collaboratively to find resources.

[7]. *Synthesise, evaluate and reflect on results.* Students share results and the tutor evaluates the learning that originated in the team. The final step is thus to synthesise, to evaluate and to provide feedback. They also discuss whether they now possess new and accurate, detailed knowledge regarding the problem. In addition, it is very important that the students validate the PBL process. The Maastricht approach is visually presented in Figure 2.4.

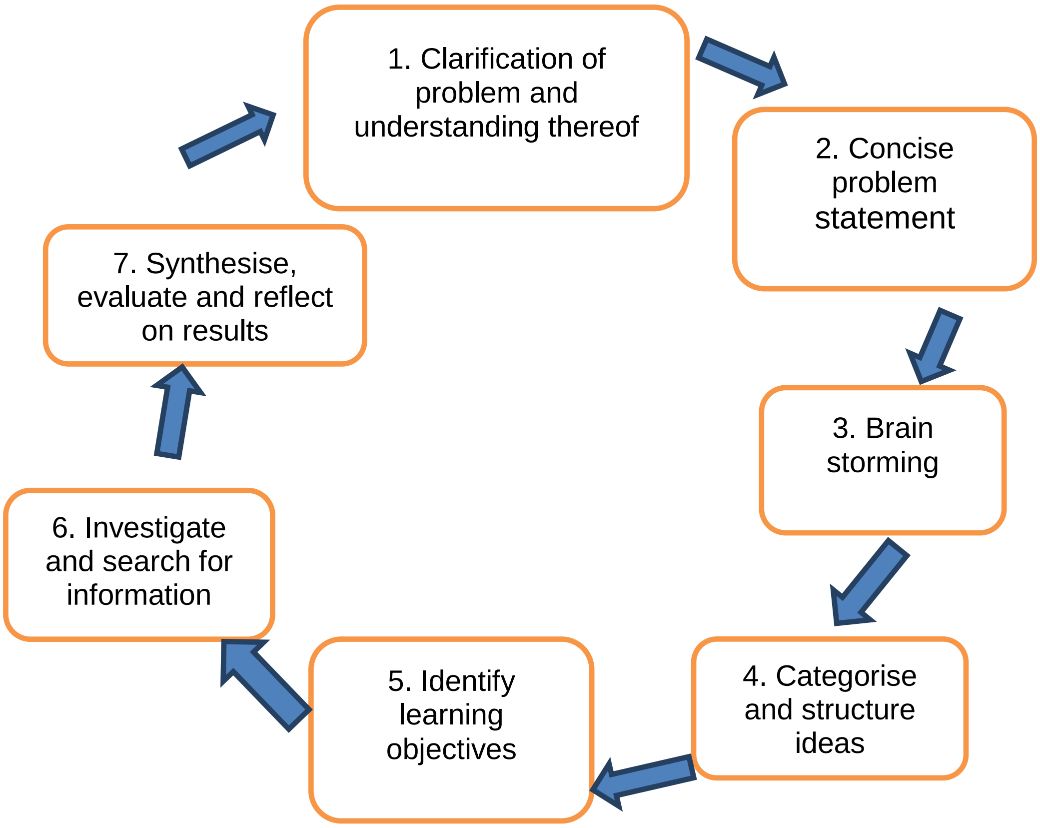

Figure 2:4: The seven-jump Maastricht approach

Source: Compiled by researcher

2.5 The context and rationale for employing hybrid-PBL in this study

Studies revealed that teaching methods do not necessarily involve independent and self-directed learning and that traditional teacher-centred instruction such as direct lectures focus mainly on passive learning (Frambach *et al*., 2012). This highlights a gap between what students learn in universities and what they need to do in practice after graduation. Research by Bagheri *et al*. (2013) focused on addressing this gap by introducing problem-based learning (PBL) or as they called it, problem-organised learning (PoBL) as an initiative element to bridge the gap between theory and practice. In other words, in order to increase the appropriateness and applicability of the content that students learn in universities, PBL is recommended as a possible means of bridging the gap (Johnson *et al*., 2016). Thus PBL could be applied as an appropriate strategy to existing educational technology courses as confirmed by Czabanowska *et al.* (2012).

Since the intervention in this research was the *first encounter* with PBL for all the participants and the researcher, the hPBL method was used. This strategy, according to Carrio *et al.* (2011) and Bofill (2016), is suitable in providing enough guidance in the learning process and in producing satisfied performance during first PBL implementation.

It should also be noted that most of the participants have no technical background (not a prerequisite) and therefore they experience the PBL environment as challenging and the PBL problems used in this study were mainly seen as **ill-structured**. Therefore, hPBL was the model of choice to implement PBL in Mechanical Technology, as students were required to develop projects while being subjected to a combination of mini-lectures and project work (Hosseinzadeh *et al.*, 2011; Jonassen, 2010) (see Chapter 5). Although students perceive the problems as a challenge, they were still responsible for particular tasks and their activities were guided by the lecturer using mini-lectures. The selected projects (see chapter 5) were aligned with the outcomes in the study guides, however students had to find and apply appropriate procedures and logical sequence of activities regarding all four projects.

hPBL was used during the two interventions to align the projects with regard to the amount of 'self-directedness' (*y*-axis in Figure 2.2) and problem 'structuredness' (*x*-axis in Figure 2.2).

Since Nielsen *et al.* (2010), considered PBL a suitable practice for an intervention in engineering education, it was used as a model to apply PBL in this study, as MT shares basic principles and methods of instruction with engineering. It should, therefore, be appropriate to implement a hybrid-PBL model in Mechanical Technology (MT) education. The two study fields MT and engineering, for example, share common goals such as bringing theory and practice together, providing 'hands-on' experiences, familiarising students with equipment and tools as well as the planning and assessing of projects (Hosseinzadeh *et al.*, 2011).

PBL, as used in this intervention, also focuses on helping students to make *their own* significances while learning, and this too can be directly linked to SDL as their focus on processes such as resourceful structure of knowledge, individual learning strategies, and evolving methods can lead to self-directed learning (Tan *et al.*, 2009). Within the hPBL approach, the problem was *based* on a question of inquiry and *structured* around the development of projects (see Table 1.1).

The four projects in the 2 interventions (see Figure 1.2 and addendums F-J) fit more or less in the middle of the scale in Figure 2.2 as all projects were between well- and ill-structured and between partially self/instructor directed and self-directed (see Chapter 5). The decision was also based on the advice provided by Kahn and O'Rourke (2005) and Deignan (2009) that suggests the use of hPBL to allow students to be guided by a lecturer by means of mini-lectures, case studies, demonstration, practical sessions, learning resources and other relevant information (Deignan, 2009; Kahn & O'Rourke, 2005; Smith, 2005).

Researchers such as Choi *et al*. (2014) strongly believe that PBL can help students develop critical thinking to solve problems and to bridge the gap between practice and theory. They, Choi *et al*. (2014) and others such as Rogal and Snider (2008) agree that PBL students should take responsibility for their own learning and that it enhances self-directed skills.

In Table 2.2 the adapted seven Maastricht steps used in this study are shown. This model is a general 'plan' that was applicable to all four projects

Table 2:2: Adapted model for hPBL project development in this study

Steps of problem-based projects	Lecturer guidance	Student application in Mechanical Terchnology
1. Conceptualise. Clarify the concepts	hBPL: Lecturer provides guidance in terms of demonstrations and mini-lectures as needed (20% - 30%)	Understand that there is more than one option to solve the problems: Clearly understand particular MT concepts applicable to the project.
2. Define the problem context. Discuss the problem context and refer to a general problem to be solved		Discuss/define the problem. Students actively discuss and reach an agreement on the challenging problems and particular details concerning this project.
3. Identify knowledge and needs (brainstorm). Identify current knowledge and learning needs to solve the problem		Prior knowledge is recalled. The what and how aspects of the problem are discussed. Students brainstorm ideas to solve the problem.
4. Categorise and structure ideas. Review steps 1 and 2. This is a collaborative approach. It leads to more creativity		Discuss problem in different ways. Provide tentative solutions. The problem should be outlined in various ways and related ideas should be discussed.
5. Formulate learning objectives and goals. Decide exactly what should be done and how		Set learning objectives for this specific project. Find examples or general information regarding the problem. The team should reach consensus regarding the learning objectives.
6. Investigate, design and develop. Focus on the innovative design and development of a solution to the problem		Students investigate and find appropriate resources. Learn how to do a specific task (e.g. weld). Share ideas and argue to find solutions, then design and develop the MT artefact to solve the problem.
7. Evaluate and reflect. Synthesise, evaluate and provide feedback. Ensure that the objectives were reached and assess each member’s responsible involvement in the project		Evaluate and reflect on design of the artefact and determine whether the problem was solved. Find and discuss ways to improve on the project. Providing feedback (possess new knowledge and skills regarding the problem).

Source: Compiled by researcher

2.6 Metacognition and reflection essential for PBL

The meaning of metacognition is ‘thinking about thinking’ or knowing how your mind works, however metacognition also involves being able to reflect and analyse, to make assumptions, ‘learn’ from the analyses, and how to put the ‘learning’ into practice (Downing *et al.*, 2009:610). Metacognitive skills (planning, monitoring, evaluating), can also be beneficial in problem solving improve academic achievement, content knowledge, and understanding (An & Cao, 2014). According to Bell (2010), students need to know how their minds work in order to solve problems. For example, students need to understand concepts, their flow of ideas and the act of thinking and re-thinking within a problem-based context.

The concept of reflection with regard to learning dates back to the work of Dewey, which emphasises the importance of ‘academic reflection’ to foster self-thinking, critical thinking and the development of values and skills (Lew & Schmidt, 2011:148). Dewey defined reflection as “active, persistent and careful consideration of any belief or supposed form of knowledge in the light of the grounds that support it and the further conclusion to which it tends” (Dewey, 1997:116). Reflection differs from individual to individual in that people interpret experiences in their own way in an effort to understand the world by means of perceptions of what happens to them, what they hear, see and read. This reference frame originates and can be formed through various experiences such as previous learning (Taylor, 2017). Metacognitive skills resulting from, amongst others, reflection and analysing aid the development of skills needed in the future (Jumari *et al.*, 2019). Metacognition is also about “taking ownership of one’s learning and maximising it” (Jumari *et al.*, 2019:90). These are essential skills and abilities needed in PBL. “PBL with a metacognitive approach organises the learning process in problem-solving activities, allowing students to convey ideas, arguments, solutions and being able to interact fully during the learning process” (Panjaitan & Hutauruk, 2019:2). As a result, students should continually monitor and reflect on their problem-solving attempts.

Cooper *et al.* (2008) and Sandi-Urena *et al.* (2011) also found the use of group interventions advantageous in fostering metacognition. The ‘problem-solving activity’ should stimulate the main aspects of general problem-solving, namely planning, monitoring the problem solving process and evaluation thereof (Ghufron & Ermawati, 2018; Reimer *et al.*, 2016; Vu, 2017).

2.7 Group work and cooperation in PBL

Group work in PBL is important as it includes various teaching and learning elements such as planning, interaction, and reflection that could enhance higher-order thinking, problem-solving skills and self-directed learning (Schmidt *et al.*, 2011; Yadav *et al.*, 2011).

According to Harden and Laidlaw (2013), *small group teaching* is by nature a more interactive learning experience, as students constantly engage with other group members, content and with the lecturer. Students learn from each other cooperatively and educators often use team sports, group projects, role play and other group activities to enhance such learning (Estes *et al.*, 2015). The use of small group teaching usually fosters ''cooperativity, knowledge, routines, skills, competencies, and abilities needed for teamwork" (Kövecses-Gősi, 2018:213). Mostly two types of *small group teaching* are used in classrooms. These are *cooperative* learning and *group-work* learning.

Cooperative learning (CL) is defined as a teaching-learning strategy "which employs small teams of pupils to promote peer interaction and cooperation for studying academic subjects" (Tuan, 2010:65). Benefits of cooperative learning are: enhancement of students' cognitive growth, motivation, interaction and learning achievement (Tuan, 2010). Cooperative learning also enables students to be effective members of a team (Johnson & Johnson, 2011; Tran, 2014).

Motaei (2014), confirmed by (Johnson *et al.*, 2014), identified five principles that are crucial to cooperative learning. These are:

- Positive interdependence. The group's success depends on the success of every individual in the group. If one fails, everyone fails.
- Face-to-face interaction. Students need to explain their own learning process to their peers, should support one another and interact with each other.
- Individual accountability and personal responsibility. Feedback should be given by individuals to the entire group with regard to individual performance.
- Social skills. Students need to develop conflict, management, leadership, and communication skills while learning to trust one another and build confidence.
- Group processing. Reflection with regard to 'how are we coping with the group work?' and 'how can we do better?'

Although not all cooperative work is group work and not all group work is cooperative work, group work is a way to organise teaching space and activities in such a way that students work together in groups when given a task and all members of the group share the equality and mutuality of the group (Johnson, 2009).

As group work is an important aspect of PBL, they have similar benefits. Both approaches use a small number of individuals who share a uniqueness, collective goals, interdependencies, distinctive roles and belonging, to do something that individuals on their own cannot do with the same efficiency (Hughes & Jones, 2011). The importance of group work and PBL, according to Havenga (2015) are to:

- break complex tasks into smaller bits and steps;
- foster time management;
- improve understanding through discussion;
- provide and receive feedback on performance (reflection);
- improve communication skills;
- challenge assumptions;
- develop skills to solve complex problems;
- learn how to delegate and share roles, accountabilities and responsibilities;
- permit students to learn from each other (collaboratively);
- find new ways to solve a problem; and
- learn how to work in a team.

A comparative summary of the aims of cooperative learning, group work and PBL adapted from Havenga (2015) is provided in Table 2.3.

Table 2:3: Objectives of cooperative learning, group work and PBL

Cooperative learning	Group work	PBL/hPBL
Promote and foster learning elements such as: • positive interdependence, • face to face interaction, • individual accountability, • personal responsibility, • feedback to entire group.	Promote and foster learning elements such as: • breaking complex tasks into smaller bits, • time management, • improving understanding through discussion, • providing and receiving feedback on performance (reflection), • improving communication skills, • challenging assumptions, • developing skills to solve complex problems, • learning to delegate and share roles, accountabilities and responsibilities, • allowing students to learn from each other, • finding new ways to solve problems, and • learning how to work in a team.	Promote and foster learning elements such as: • knowledge structuring, • reasoning, • self-directed learning skills, • intrinsic motivation, • construction of knowledge, • student engagement with content, • students' sense making of their knowledge, • lifelong learning, • solving authentic problems, • investigation and collaboration, • academic scaffolding, and • reflection.

Source: Adopted from Havenga (2015)

The *learning elements* corresponding with group work, cooperative learning and PBL are: taking responsibility for own tasks, conducting research, working in small groups, integrating knowledge and skills, taking ownership of own learning, engaging with the problem, and motivating and encouraging students (Barrows & Tamblyn, 1980; English & Kitsantas, 2013; Savery, 2015; Walker *et al.*, 2015; Wang *et al.*, 2017).

According to Nariman and Chrispeels (2016), several concrete benefits of group work have been identified, namely:

- higher educational achievement;
- increased attendance;
- increased motivation;
- improved group to group relationships; and
- improved communication skills.

2.8 High knowledge and skills

It was established that students' high knowledge and skills could be advanced by using strategies such as PBL in order to enhance SDL (Al-Shehri *et al.*, 2018). High knowledge and skills such as adaptive thinking, collaboration and critical thinking are needed by each individual to prepare for the fourth industrial revolution (4IR) and to develop opportunities for innovation (Collins & Halverson, 2018; Gibb & Walker, 2011). Approximately 65% of current students (world-wide) will be employed in jobs that do not yet exist (Darling-Hammond *et al.*, 2015). The aim of any educational institution should be to prepare students with knowledge and skills for future demands (Olson & Riordan, 2012). These future employees need high levels of knowledge and skills and, according to Graham *et al.* (2013), this can be achieved by helping students develop skills for the uncertain future by teaching and advocating high knowledge and high skills. Examples of these are, according to Davies *et al.* (2011) and Pompa (2015):

- adaptive thinking to accommodate the digital age;
- communication skills to prepare for the use of a variety of new and future ways to communicate;
- collaboration skills enabling future employees to work in teams to accommodate the cooperative nature of new job opportunities;
- critical thinking and problem-solving skills to face a rapidly changing world;
- personal management in order to plan, organise and work independently;
- inquiry skills enabling workers to 'ask the questions' for preparation for a culture;

- technology skills to be able to use modern digital work utilities;
- creativity and innovation correlating with problem-solving, inquiry and critical thinking skills;
- basic human skills such as time management and self-organistion; and
- empathy to learn how to see something from someone else's viewpoint in order to help understand their feelings and opinions.

Most of the characteristics of 'high knowledge and high skills' learning correspond with the aims and characteristics of SDL and PBL (section 2.3 and 3.3). According to AlBuali and Khan (2018), lecturers should apply PBL in their classes when opportunities to do so arrive.

2.9 Assessment of PBL

Assessment in classrooms is a process whereby educators measure what students are learning and how thoroughly they have learned it (Angelo & Cross, 2012). Assessing PBL serves the same general purpose however, according to Salinitri *et al.* (2012), PBL is aimed at conveying evidence-based conclusions, developing problem-solving skills, and enhancing communication skills and assessment thereof should focus on these three development areas.

Conveying evidence-based conclusions is a form of assessment where examples of evidence or proof of an individual's competencies or abilities are gathered to show the results of his or her skills (Youngstrom *et al.*, 2015). Evidence-based assessment is used in many disciplines, such as education, medicine, law and nursing, and may involve portfolios, simulations, skills evaluation, and self- and peer assessments (Byrne *et al.*, 2009; Youngstrom *et al.*, 2015). Assessing problem-solving skills is a process to determine the capacity of a student to successfully complete each PBL step (see Table 2.2). Communication skills include verbal and nonverbal expression, response to others regarding feelings and needs, and the degree of focus.

Assessing the development of problem-based learning should focus on what students can do and not what they can remember (Angelo & Cross, 2012). Hesse *et al.* (2015) divided assessable PBL skills into two categories, namely *social process skills* and *cognitive process skills*. The social process skills are the abilities needed to *manage the* *people* (including oneself), working on a project while the cognitive process skills are the abilities needed to *manage the problem* (Hesse-Biber, 2010). Hesse *et al.* (2015) further identified five underlying skills with regard to *social process skills* and *cognitive process skills* namely:

- *Participation skills*. These are skills with regard to *becoming part of the community of practice* which focuses on 'action, interaction and task completion';
- *Perspective taking skills*. This is a multidimensional construct on affective level, linking with empathy and emotional understanding of others with regard to the quality of the interaction;
- *Social regulation skills*. This is the learning potential that lies in the diversity of a group and the potential diversity that individual members bring to the interaction. The main frame of collaborative problem-solving rests on metacognition, trans-active memory, negotiation abilities and the ability to take initiative;
- *Cognitive process skills* such as task regulation skills referring to *planning* which is one of the core activities in PBL. Planning involves the formulation of hypotheses in goal reaching and selection of action steps to solve the problem. This also includes reflection;
- *Learning and knowledge building skills* involving collaborative problem solving, whereby individuals learn to deal with dead ends, to coordinate, collaborate and negotiate with others.

2.9.1 Selection of appropriate assessment methods of PBL

When planning and selecting assessment in a PBL classroom, one should remember the importance of assessing the individual learning outcomes of students and not the team project (Howard *et al.*, 2016). One important aspect of assessing PBL is to remember that the assessment should be performance-based and all-inclusive in order to allow room for students to make their own decisions and find their own solutions (Daud, 2013).

But how does assessment of PBL differ from other assessment? In reality, assessment for PBL should be a process whereby information regarding a student's performance is collected, and it should be characterised by:

- Validity and reliability. According to Sullivan (2011), the validity of assessment or test is not a property or result of the assessment but rather a clarification of how accurate the test or assessment measured the underlying outcomes in a particular learning context. Reliability is an indication of the ability of the assessment tool or test to achieve similar results each time it is used. Thus good validity and reliability can be obtained over time, with practice and with known assessment methods.

- Collection in a continuous ongoing manner. A good continuous and ongoing assessment tool that can be used in PBL is daily or weekly reports and peer and self-assessments which should also provide useful information with regard to improving learning and evaluation in future (Mawdesley et al., 2011).

- The ability to measure outcomes according to clearly stated criteria. Assessment criteria provide students with information with regard to the qualities, features and other characteristics of an assessment or test to be used in measuring their outcomes on a specific topic. Assessment criteria thus explain which aspects would be considered when making decisions about their performance in a test (Lefoe, 2013). For example, students need to know and understand the aim of the learning experience, the motivation thereof, their current position with regard to the aims and how their goals can be achieved.

- Collection of evidence by means of a variety of methods. Examples of assessment methods are feedback surveys, course or project evaluation, written tests, peer group meetings, simulations, and educator assessment (Minin *et al*., 2015).

- Reports that provide feedback to parents, students and teachers. According to Evans (2013): Feedback [negative or positive] is seen as facilitative in that it involves provision of comments and suggestions to enable students to make their own revisions and, through dialogue, help students to gain new understandings without dictating what those understandings will be. Assessment reports therefore should provide useful information to parents, teachers and students with regard to the student's academic progress.

- Integration into the learning process. Because students become more diverse culturally, socially and academically, educators need to integrate teaching and assessment and apply various teaching and assessment methods (Schwarzer, 2009).

- Focus on what students can do and not on what they can remember by testing their abilities to apply what they know rather than tell what they know (Wiggins, 2011).

As long as the educator keeps the purpose and characteristics in PBL assessment in mind, the following assessment methods (see Table 2.4) could be appropriate for the assessment of PBL activities. Table 2.4 was adopted from the ideas of Schwarzer (2009) and Angelo and Cross (2012).

Table 2:4: Suggested assessment methods for PBL

* Assessment	Examples
***Exams**	Written, practical
***Tests**	Written, practical
***Proposals**	Oral or written reports, debates, narratives, descriptions, research and surveys in the form of reports, essays, drawings or posters
***Construction, making designing and demonstrations**	Written, practical
***Projects**	Group work – needs planning, research, discussions and proposals (for example, planning an artefact)
Portfolios	Proof of what has been done in a book, file or report
Student or learner profile	Oral reports, debates, narratives, descriptions, research and surveys in the form of reports, essays, drawings or posters
Observation	Teachers or educators observe day-to-day activities with regard to learners' or students' approach and progress. (For example – hand and foot placement, hand and eye coordination, skills level, etc.)
Interviews	Oral about work or a take home questionnaire
Self-reflection	Student looks back (honesty, criteria and reliability can be suspected)

Source: Compiled by the researcher

*Focus on high levels of Bloom's taxonomy

According to Angelo and Cross (2012), the assessment 'tools' in Table 2.4 can be used successfully to assess PBL activities.

2.10 Factors determining the success of PBL implementation

Implementation of PBL, may according to Abdalla and Gaffar (2011); Graham and Crawley (2010) be dependend on the presence of absece of the following (see Table 2.5).

Table 2:5: Factors influencing the implementation of PBL

Factors that may enhance the successful implementation of PBL
• Prior knowledge, a constructivist element. The amount of prior knowledge and the ability to activate it is important for successful PBL; • The quality of the problem can initiate and stimulate discussion and the PBL process; • Tutor behaviour that steers and keeps discussions within the context can increase the quality of the problem and the PBL process; • Student motivation should lead to self-determination for learning; • Teamwork as a well-functioning team should increase collaboration and ultimately PBL effectiveness; • Group dynamics should ensure the participation of all team members to improve group work, and • Rules of engagement (ground rules) to maintain group dynamics.
Factors that may hinder the successful implementation of PBL
• A quiet, shy student who seldom contributes to discussions; • Students who are absent or late for classes; • Dominant students who can overrule others in a team or group; • Tutor not well prepared; and • Conflict between students with different personalities.

Source: Compiled by researcher

In developing countries such as South Africa, there are other unique challenges regarding employing the PBL approach. According to Nariman and Chrispeels (2016) and AlBuali and Khan (2018), these are:

- how to accommodate large numbers of students;
- a need for classroom space to accommodate PBL activities;
- a shortage of available electronic classroom aids such as computers and internet access;
- a general resistance to change;
- how to supply enough and well-qualified educators;
- how to fund the implementation and new curriculum;
- how to manage the information overload;

- how to identify and set priorities with regard to curriculum content; and
- how to motivate all stakeholders for self-directed learning.

These are general challenges (of which the researcher faced a few) when employing a PBL approach in developing countries such as South Africa. While the researcher did not have the answers at the time, he hoped to shine some light on the challenges while developing a new model for PBL in MT (see Figures 7.2 and 7.3).

2.11 Conclusion

To summarise this chapter: the main theory for understanding PBL have come to mind. This is the constructivist theory that includes concepts such as *active learning*, *social learning, creative learning,* and *self-development.* It is also clear that the different learning theories of researchers such as Vygotsky, Piaget, Marx, Rogers, Dewey and others all agree on basic truths with regard to learning, as they all support the concepts of addressing open-ended problems, active involvement in learning, construction of knowledge, self-directedness and team work. A theoretical framework highlighting the characteristics of problem-based learning was provided in Chapter two. This included different PBL models to set the background for implementing and assessing problem-based learning in classrooms. In Chapter 3, the researcher will outline the importance of self-directed learning (SDL), the link between SDL and PBL as well as SDL in Mechanical Technology (MT).

CHAPTER 3: SELF-DIRECTED LEARNING: A REQUIREMENT FOR MECHANICAL TECHNOLOGY EDUCATION

3.1 Introduction

The aim of this chapter is to outline self-directed learning, related approaches, the role of problem-based learning in self-directed learning, as well as the development of self-directed learning in Mechanical Technology. During the last decade, references to learning often included words such as self-directedness, self-regulation and self-directed learning (SDL) (Kirk *et al.*, 2012). As can be derived from the term 'self-directed learning', it is controlled by the 'self' and it includes some form of 'learning' (Brockett & Hiemstra, 2018). SDL is not an intellectual achievement or an academic result. It is rather an acquirable mental ability, allowing individuals to convert intellectual skills into task-related academic skills (Griol *et al.*, 2014). The notion that learning should be dynamic or active or *self-directed* is well-known, but there is often a lack of agreement about exactly what SDL entails (Benvenuti, 2013). However, SDL is interchangeably associated with active involvement, responsible knowledge construction and extension of cognitive processes (Chi, 2009; Wang, 2011).

3.2 Theoretical approaches

The quest to find how students manage their own learning resulted in theories about self-directed learning (Zimmerman, 2013). In the mid-twenties, research in educational psychology revealed that there were significant differences between the learning results of children and those of adults, which led to the understanding of adult learning. As a result, theories such as andragogy, heutagogy, self-regulated learning and SDL emerged (Merriam & Bierema, 2013; Taylor & Kroth, 2009). The use of learning theories may guide educators to select, design, implement and assess learning opportunities tailor-made for current and future teaching needs (Du Toit-Brits, 2018).

A brief overview regarding some theories is provided, with the focus on SDL.

3.2.1 Andragogy, Heutagogy and Self-regulated learning

The word **andragogy** (*andra,* meaning 'man'; and *agogos*, meaning 'learning') refers to the *art and science* of assisting adults to learn, as well as ways of describing the adult learning process (Staff, 2011:18). Malcolm Knowles popularised the word ‘andragogy’, and according to him and others, andragogy is based on five assumptions (Knowles, 1990; Knowles *et al*., 2012; Merriam, 2001; Ozuah, 2016), namely an adult learner or student –

- possesses independent self-concept in directing his or her own learning;
- has collected a reservoir of life understandings that serves as a source for learning;
- possesses learning needs associated with the learning environment;
- is problem-centred and is engaged by the application of knowledge; and
- is motivated to learn as a result of internal rather than external factors such as motivation.

Merriam (2001) confirmed that andragogy focuses on adults involved in formal and informal learning actions to satisfy some apparent requirement or concern. She also agreed that adults pose an autonomous self-concept and that with practice, adults should become progressively more self-directed. Adult learning therefore is the ‘level of preparedness’ that students reveal to allow them to engage in the learning process (Durall & Gros, 2014:283; Wlodkowski & Ginsberg, 2017).

Although andragogy acknowledged the concepts of self-concept, prior learning, change, application of knowledge and intrinsic motivation, it fails to satisfactorily address reflection and extrinsic motivation (Conaway, 2009).

Another adult learning theory, **heutagogy**, was defined by Hase and Kenyon in 2000, as the study of self-determined learning or a form of self-determined learning rooted in andragogy (Blaschke & Hase, 2015). In a heutagogical approach, students are seen as autonomous and self-determined, and the focus is on the students' capacity to learn as well as the ability to assess themselves (Abela, 2009; Blaschke, 2012). Heutagogy explains the concept of life-long learning in a thriving work environment (Kamenetz, 2010).

Canning (2010) labelled heutagogy as the process whereby students motivate and enable themselves to investigate and apply their own learning to accommodate a change in thinking within themselves and those working with them. Heutagogy is thus comparable to SDL, as a self-directed and self-determined approach in which students reflect on learning and educators teach students how to teach and assess themselves. Although heutagogy is currently used in a number of universities, it is more suited to distance learning (without direct lecturer contact), as well as the student-guided assessment, because the characteristic thereof does not make it attractive for full-time contact-based education (Blaschke, 2012).

Theory and research with regard to self-regulated learning (SRL) developed in the mid-1980s in an effort to provide answers to the question of how students develop into masterful *own-learning* managers. The concept 'SRL' originates from educational psychology and cognitive psychology, whereby 'SDL' originates from describing the learning activities "outside traditional school environment" (Saks & Leijen, 2014:192). According to Broadbent and Poon (2015), SRL is based on the following principles of self-learning: metacognition, peer learning, time management, elaboration, rehearsal, organisation, and critical thinking.

Another view of self-regulated learning is that of Zimmerman (2000 cited in Dabbagh & Kitsantas, 2012:6), namely –

> *[S]elf-regulated learning is the student's ability to independently and proactively engage in self-motivating and behavioural processes that increase goal attainment, where students must know how to set goals, what is needed to achieve those goals, and how to actually attain these goals.*

Cho *et al.* (2010), in agreement with Zimmerman, also describe self-regulated learning as a three-stage cyclical process attempting to enlighten why and how students achieve academic success. The stages are:

- The 'fore-thought' phase where students engage in learning by using their existing predetermined (positive or negative) beliefs with regard to the study topic to set goals;
- The 'action or performance' phase where students begin to engage in the required behaviour needed to achieve their pre-set goals; and
- The 'reflection' phase when students succeed in judging (reflect on) their performance in relation to the pre-set goals. The last step will determine the next

step. For example, if the goals have not been achieved, the learning will go into a cycle back to stage one or two, until the outcomes are satisfactory.

Self-regulation, however, fails to fulfill all the requirements of enhancing SDL, as only a small number of students ever become effective self-regulators. One can thus not assume that, when using SRL, students will necessarily become self-regulated students (Hakim & Sara, 2017). This is confirmed by Ormrod (2012:357) who found, "if a person experiences failure and decreased self-efficacy, it could affect their ability and desire to self-regulate". It is also true that a student can become successful without becoming self-regulated (Bercher, 2012).

3.2.2 Self-directed learning

Malcolm Knowles, a well-known American adult educator, officially introduced the concept SDL. The roots of SDL can be traced back to the sixties and linked to the problem-based (PBL) programme of McMaster (Leary, 2012). In other words, the SDL concept and the application thereof were influenced by elements of *PBL* when used at McMaster before the term 'SDL' became commonly known. It is also indicated that Knowles (while studying in the fifties) used the words "self-directed learning" freely long before they were officially published by others (Servant, 2016).

The belief of SDL goes back to the existentialist viewpoint that links individual sovereignty, obligation and personal opinions to the learning process, implying that learning itself should reward a student to become an unhampered, mature and trustworthy self-learner (Loyens *et al.*, 2008a; Thomas *et al.*, 2016). SDL is also *internally regulated* by the students themselves, thus implying that with SDL there is no external control of learning, as the leaning is internally self-esteemed, self-regulated and self-motivated behaviour, resulting from interest and satisfaction in the activity (Metsärinne *et al.*, 2015; Zhang *et al.*, 2010). SDL is a self-instructed process through which students convert their academic skills in a *self-do* understanding of a teaching and learning experience (Zimmerman, 2013).

Other older perspectives of SDL are, according to Brookfield (1993:229), "self-teaching" based on "the assumption of the learner for planning and directing the course of learning", while Caffarella (1993:25) describes SDL as a "self-initiated process of learning" whereby the capability of individuals to plan and manage their own learning is the main focus.

According to Boustedt *et al.* (2011:62), SDL is “self-controlled, deliberate and an intended form of natural learning”. Knowles *et al.* (2012) added to this, by stating that SDL involves students taking responsibility for their own learning processes. Knowles (1975) further added that SDL is a practice in which individual students identify their own learning requirements, set their own learning objectives, identify appropriate learning resources, employ suitable learning strategies, and assess their own learning outcomes with or without the help of others. Therefore, SDL refers to students who are capable of determining their learning needs and objectives, selecting and implementing suitable learning approaches, and evaluating learning outcomes (Beckers *et al.*, 2016). According to Chou (2012), SDL refers to a learning process that is pursued, intentional and conducted by the student in an independent way.

Researchers and scholars, such as Hong and Park (2012), Mansor (2009), Wu *et al.* (2012), however agree that SDL includes one or more of the following:

- mature students who have the self-concept to steer their own learning;
- the use of a rich pool of life experiences that can be utilised as a reserve for learning;
- students who can adapt their learning needs to a particular learning environment;
- focus on addressing problems;
- planning, completing and evaluation of learning experiences;
- freedom to individuals with regard to their unique learning experience;
- adults who are ready to take control of their own learning;
- lifelong learning;
- enhancement of technological skills;
- interest in instant application of knowledge; and
- motivation to learn by means of an inner self-regulated process rather than an external process.

SDL is also a dynamic approach providing opportunities to clarify and describe the adult learning process (Saks & Leijen, 2014). Scholars are of the opinion that self-directed learning can be enhanced by praxis such as an authentic learning environment, blended learning, metacognition, cooperative learning, contextualised learning, as well as problem-based learning (Herrington *et al.*, 2014; Merriam & Bierema, 2013; Zohar & Barzilai, 2013).

SDL further emphasises learning as a self-action where students reveal their learning abilities in practical ways and not as a result of teaching experiences (Merriam & Bierema, 2013). The theory of SDL is also based on the assumption that if students display some sort of individual initiative, willpower and ability in pursuing learning, they possess self-directed tendencies (Frick *et al.*, 2010; Zimmerman & Schunk, 2013). Although SDL theories can be linked to information processing, social cognitivism, Vygotskian, and cognitive constructivist theories, all these theories agree on similar aspects of SDL (Breed, 2013; Corno, 2013). According to Zimmerman and Schunk (2013), the extent of students' self-directedness aligns with their degree of metacognitive skills, their personal motivational behaviour, their willingness to pursue learning, as well as their ability to self-manage their learning.

The SDL theory also promotes and sustains learning how to learn, lifelong learning and gaining metacognitive skills with regard to learning efforts (Samarasooriya *et al.*, 2019). Learning how to learn involves knowing that the human brain needs practice in order to function properly, and that it needs interruption between different learning experiences in order to process and memorise new knowledge (Doyle & Zakrajsek, 2018). Lifelong learning refers to individuals' ability to maintain and improve their capacity to work and function effectively throughout life. Metacognitive skills denote the conscious reflection of individuals on their own cognition processes or awareness of their doing (Billett, 2010; Sáiz-Manzanares & Montero-García, 2015).

A comparison of the different SDL-related theories, the concepts thereof and their timeline are provided in Table 3.1.

Table 3:1: Comparing different SDL-related theories

Learning theory	Key concepts	Researchers and timeline
Andragogy	Five assumptions, namely: • Independent self-concept to steer own learning; • Accumulation of life experiences as a learning resource; • Learning needs closely related to changing learning environments; • Problem-centred and interest in application of knowledge; and • Internal rather than external motivation (Knowles, 1990; Knowles *et al.*, 2012; Ozuah, 2016).	Houle, Tough, and Knowles in 1968, but first used by Alexander Kapp in 1833 to describe adult learning (John, 2009; Knowles *et al.*, 2012).
Heutagogy, also called truly self-determined learning	Six assumptions, namely: • 'double-loop learning'; • capability development, not competency development; • learner-determined, not learner-directed; • learner-managed, not instructor-learner managed; • having a non-linear and not linear design; and • focusing on understanding how to learn, not learning content (Hase, 2016).	Hase and Kenyon in 2000. Based on work of Carl Rogers, Vygotsky and constructivism (Hase, 2016).
Self-regulated learning (SLR)	Consists of three phases, namely: • Forethought phase: - Goal setting - Strategic planning - Self-motivation • Performance (learning) phase: - Self-motivation - Self-monitoring • Self-evaluation phase: - Self-satisfaction - Self-evaluation	Zimmerman in 1986 (Cosnefroy & Carré, 2014). (Zimmerman & Schunk, 2013)

Learning theory	Key concepts	Researchers and timeline
Self-directed learning (SDL)	Assumptions of SDL. A learning process in which students: • Take initiative, with or without the help of others; • Analyse their own learning needs; • Formulate learning goals; • Identify social and physical resources for learning; • Choose and implement appropriate learning approaches; and • Value own learning (Knowles, 1975b:18).	Merriam (2001), Brockett and Hiemstra (2018) and Kasworm (2011)

Source: Compiled by researcher

3.3 Teaching in support of self-directed learning

According to Du Toit-Brits (2018), individual students' self-directedness can be found in *five varieties of individual characteristics*, namely SDL talent, student motivation to learn, performance objectives, intrinsic and extrinsic objectives, and self-awareness of own learning needs. By focusing on these five areas of individual characteristics, educators should be able to enhance students’ self-directed learning by creating appropriate opportunities. The *five varieties of individual characteristics* form a complex interlink in the mind of a person. For example, the SDL ability or talent of an individual refers to the capacity or inclination to be trustworthy, consistent, organised and goal orientated (Lee *et al.*, 2010). Student motivation to learn in a self-directed manner arises from their ability to set learning goals, while their manner of setting performance objectives can be linked to their original reason for learning and their SDL ability (Du Toit-Brits, 2018). The suggested steps mentioned by Du-Toit Brits to enhance SDL in classrooms was adopted for MT and are outlined in Table 3.2.

Table 3:2: Promoting SDL (adapted from Du Toit-Brits, 2018)

THCSDL model (Du Toit-Brits)	Application in Technology
Students' individual learning characteristics	Use (general) teaching strategies promoting motivation. For example set goals, provide direction, use effective communication and set high expectations.
Teaching and learning environment	Put emphasis on independence, facilitate learning, make students feel they belong in class and empower students with knowledge, enhance ownership of learning.
Meaning-making process	Encourage students to identify their learning needs (what would you like to know, and why do you need to know this?).
Transformative, continuing SDL	Test for SDL readiness and promote higher-order thinking as well as lifelong learning by means of appropriate strategies (such as PBL).

In order to support self-directed learning, facilitators should, according to Thoonen *et al.* (2011), move gradually from traditional teaching to a student-organised learning experience, concentrate on knowledge construction, pay attention to emotional facets of learning and deal with the learning processes and results as collective occurrences. In addition, educators should be *pedagogically content-wise* to enhance students' SDL by using activities and teaching and learning strategies focused on the improvement of the five individual characteristics. These are activities such as: promote participation in self-organised activities, rather than follow orders; integrate knowledge, rather than memorise it; communicate and respond, rather than listen; understand facts and terms, rather than know them; apply theory, rather than remember it, and become independent, rather than teacher dependant (Guglielmino, 2013). Guglielmino (2013) stressed that changing a traditional teaching approach to a more SDL-orientated approach is a slow process and advised that specific steps be taken to integrate the development of SDL capabilities into a curriculum. These steps include, among others, the application of teaching methods known to enhance SDL, e.g. PBL, encourage students to learn independently, motivate learners and encourage them to take ownership of their learning.

According to Francom (2010), educators can apply four principles in class to enhance the development of SDL skills. These are:

- Match the level of required self-directedness during a learning activity to the students' readiness for SDL. This may include the students' ability to set their own learning goals, learning outcomes, learning pace and select appropriate assessment methods for a particular learning experience;
- Advance from educator-directed learning to student-centred directed learning. Starting with SDL activities suddenly can be confusing to students, and educators should, therefore, move gradually from educator-directed learning to SDL;
- Assist and motivate students to acquire subject-supporting resources and study material and develop SDL skills at the same time, as there is a relationship between the acquisition of subject material, knowledge and self-direction; and
- Encourage students to practise SDL in the teaching and learning environment by allowing them to apply SDL to specific (educator-selected) tasks (learn as you do and do while you learn).

3.3.1 The rationale for self-directed learning in the real world

Currently most people, including students and learners, find it difficult to navigate their way amongst loads of information, to keep up with very active social programmes, to meet high academic expectations and to cope with non-stop inputs from various outside sources, such as Twitter, Facebook and other social media platforms (Crozier *et al.*, 2008). According to Gabrielle *et al.* (2006), Guglielmino (2013) and Wehmeyer and Schalock (2001), self-directed **learning in the real world** is indisputably connected to life satisfaction, educational success, and workplace performance. Being successful in life can be linked to the measure of self-directedness that individuals possess, as was found (for example) in studies with regard to musicians, artists, artisans, surgeons and others (Cottrell, 2013).

Brockett and Hiemstra (2018), Guglielmino (2013) and Warner (2006) argue that self-directed learning skills and lifelong learning are needed for professional, personal, organisational and family survival as well as for the survival of communities and different countries. This makes sense if one considers the vast amounts of available information, the rate at which new information is produced, the never-ending changes with regard to technology and the rate of globalisation.

In order to become self-directed and experience the advantages thereof in a learning environment, students should change their learning behaviour and *take ownership* of their learning processes. This *change in learning behaviour* should also focus on academic skills and modern educational practices, such as dealing with information, facing the availability of huge amounts of information, accessing information and screening of relevant information (Khaled, 2014).

Educators can assist students to take ownership and learn independently by organising a learning environment that promotes self-directed learning (Kistner *et al.*, 2010). Francom (2010:32) agrees that "self-direction in learning is a product of both the external characteristics of an instructional process and the internal characteristics of the learner". Other research agrees with Kistner *et al.* (2010), stating that a student's ability to self-direct their own learning can be fostered by implementing appropriate teaching-learning strategies that is beneficial to SDL development (Brockett & Hiemstra, 2018; Jossberger *et al.*, 2010).

Awareness of the connection between SDL and a successful career can, therefore, highlight the need for SDL skills to be included in all educational institutions (including teachers' education) to address the need for future success, creativity, motivation and lifelong learning (Cottrell, 2013; DBE, 2014a). Innovators known for their success usually have SDL skills such as:

- Self-information (critically assess information in books, magazines, newsletters, specialised journals and websites) (Zimmerman, 2013);
- Experiential learning (self-reflection practices that make it possible to transmute knowledge into learning) (Ghaye, 2010); and
- Learning with or from others (a method that is associated with success and action) (Pape *et al.*, 2015).

Although, according to Francom (2010), students can demonstrate SDL in one area (such as a subject) while having no SDL in another area, the researcher believes that self-directed behaviour can also be initiated in a child's behaviour at an early stage by parents, teachers and other role-players. An example of this are parents constantly reminding, motivating and helping small children to start their homework on time, to plan activities well in advance and to reward appropriate behaviour in this regard. Parents, teachers and other stakeholders should also be able to reinforce self-directed behaviour by setting an example of time management, motivation and perseverance as well as highlighting the advantages thereof.

Devi *et al.* (2016), Frambach *et al.* (2012), Havenga *et al.* (2013), and Kicken *et al.* (2009) identified other methods that can be used in classrooms (presumably also MT classes) to build and support an SDL climate.

Proclaim the need for self-directed lifelong learning:

- create partnerships with students;
- value each question students ask;
- focus on positive reinforcement in classes;
- show passion and enthusiasm for learning;
- promote awareness of the self in self-directed learning by means of learning-style assessment (make the student aware of his or her own learning style);
- do self-directed readiness tests with students;
- make students aware of what they have learned, are learning and are going to learn;
- use problem-based learning, project-based learning and field-based learning;
- encourage reflection, metacognition; and
- use assessment strategies that build SDL skills and abilities.

Modern-day educational theories and practices tend to highlight essential skills, such as self-directed learning, and agree on the fact that self-directed learning is one of the most effective ways of learning (Fahnoe & Mishra, 2013). Knowles (1975), Brockett and Hiemstra (2018) as well as Kolodenko (2015) found that individuals who take the initiative to learn by themselves tend to learn more and better than those who do not, and that people who display more self-directed learning conduct tend to perform better academically than those who do not.

Educators need to be knowledgeable in assessment and instruction in order to meet the intricate demands of using assessment and instruction as means to affirm, extend and account for student learning (Edwards, 2017). This should be applicable to all learning environments, including MT. Therefore, the development of SDL in classes should have a favourable result with regard to life fulfilment, academic achievement and job satisfaction. There is conclusive evidence in the literature to highlight this contention regarding the value of SDL in classes (Kolmos, 2007).

3.3.2 Holistic continuing self-directed learning

As outlined by Du Toit-Brits (2018:53), students can transform holistically to "self-directed lifelong goal-orientated students" by changing their learning characteristics, the learning environment, and a meaning-making learning change process. She calls this Transformative and Holistic Self-Directed Learning (THCSDL). The concept of this SDL model is outlined in Figure 3.1 (Du Toit-Brits, 2018).

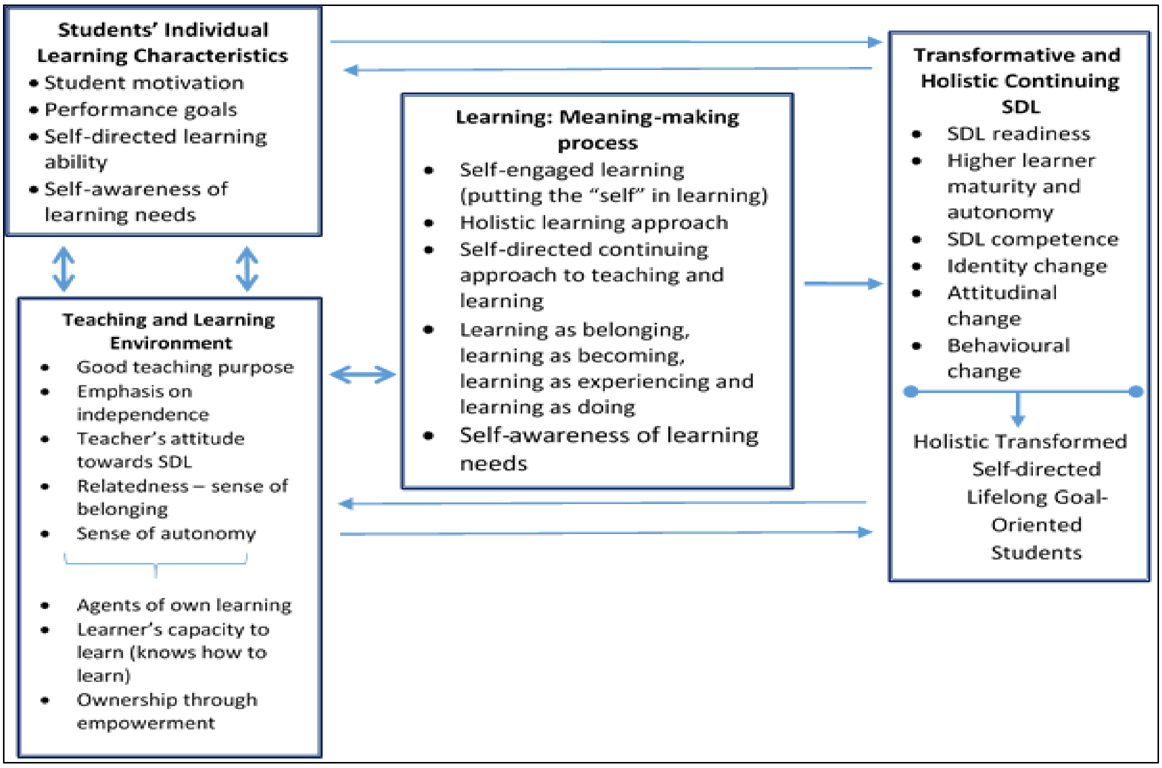

Figure 3:1: Transformative and holistic continuing self-directed learning (THCSDL) (Du Toit-Brits, 2018:55)

Du Toit-Brits (2018) identified four important contributing variables in establishing a holistic self-directed classroom culture (Figure 3.1).

Individual learning characteristics denote characteristics such as student motivation, goal setting, self-directed learning ability and self-awareness of learning needs (Du Toit-Brits, 2018). The meaning-making process is more complex, as this refers to the students becoming more capable (change in behaviour) to learn as a result of taking ownership of their own learning by applying SDL.

Ownership of learning also refers to a student's ability to go beyond simply following the directions of an instructor/teacher, as students who own their learning are more likely to complete complex tasks, solve problems and generate high quality work (Conley, 2014). These students are usually successful in various types of learning environments, are highly motivated and believe in their own abilities even when they have limited contact with instructors (Conley & French, 2014). Taking ownership of learning is an important aspect of SDL and involves according to Lee *at al.,* (2010) the act of sitting down to study (spending time learning) and being responsible for your own knowledge acquisition. Ownership of learning also implies that each individual should aim to learn actively and effectively (Gorghiu *et al.,* 2015).

A meaning-making process (change) in learning involves students becoming more acquainted with a deep approach to learning and cognitive processing (see 2.1 and 2.2.2) (Du Toit-Brits, 2018). Educators can enhance *meaning-making* by laying an SDL foundation (awareness of self in learning), applying a holistic learning approach to creating a cooperative learning environment, providing constant support and facilitating student initiatives and by highlighting the self-awareness of learning needs (Benvenuti, 2013). Transformative, holistic, continuing SDL involves the application of totality (the inclusion of human experiences such as reflection of the student or teacher in teaching and learning) as well as content to promote intrapersonal, interpersonal and interconnections to enable students to develop to their own potential (Du Toit-Brits, 2018).

For this study, the focus of SDL enhancement is mainly on the *teaching and learning environment, students' individual learning characteristics* and *learning as a meaning making process* as described by Du Toit-Brits (2018) in Figure 3.1, as these are the variables that the educator facilitates in order to enhance SDL. This involved an intervention to change the learning environment with regard to:

- the practice of appropriate teaching strategies (e.g. hPBL);

- self-engaged learning and awareness of learning needs;
- creating a sense of belonging and autonomy in order for students to become agents of own learning, develop the capacity to know how to learn and take ownership of learning by means of empowering themselves; and
- increasing student motivation and self-awareness towards SDL.

3.4 Assessment in a self-directed environment

It is important to distinguish between assessment of *classroom activities* promoting SDL skills and assessment of *SDL abilities*, also referred to as *assessment for learning* and *assessment of learning* (Philpott, 2012). Assessment ***for learning*** involves the use of SDL measuring instruments to assess the measure of SDL readiness before or after a task or project (Timothy *et al.*, 2010). According to Hayward (2015), assessment ***of learning*** involves gathering evidence from students in various ways to determine whether learning occurred in order to make informed decisions with regard to the next steps for instruction.

Numerous studies have shown that a measure of self-directedness or ability to learn in a self-directed manner is a skill that not only has an influence on career success but also on academic achievement and should, therefore, be mastered at an early stage of life (Hung & Loyens, 2012). Researchers found a positive relation between grade mark averages and the Self-Directed Learning Readiness Scale (SDLRS) scores (Slaughter, 2009). It is also true that teaching methods such as PBL/hPBL should have a positive result with regard to self-directedness and scholarly achievement (Loyens *et al.*, 2008a). Correlating with the findings of Slaughter (2009) and Loyens *et al.* (2010), it was recently found when scrutineering high scorers' results of SDLRS tests that there is a link between high scorers (high SDL levels) and people in high profile jobs, such as entrepreneurs and business executives (Guglielmino, 2013).

When assessing one should aim to assess students' performance or their demonstrations of applied knowledge where students are assessed to see if they are ready for the next level of learning rather than testing their ability to remember (Boss, 2012). Students should be able to explain what they were doing and how activities are related to the project goal.

According to Trauth-Nare and Buck (2011), daily or weekly reports are another effective way to hold students responsible and gather formative information with regard to PBL and SDL skills. Daily or weekly reports can also provide valuable insight about problem- and project-based learning and students' progress. Well-timed reports could thus allow educators to make instructional adjustments and decisions (Trauth-Nare & Buck, 2011). Educators should provide time for students to reflect on their work and those of peers by means of well-structured criteria, as revealing student ideas in comments and constructive feedback for their peers can provide assessable information. Peer and self-assessment do not have to take place at the end of a PBL session, but can be done several times during the learning period (Gedye, 2010; Omorogiuwa, 2012).

3.4.1 Assessment *for* learning

One of the key factors when implementing classroom activities to enhance self-directed learning is to establish whether students have the ability to engage in SDL activities and to determine whether students' SDL skills improved with the use of some educational strategy (Cheng *et al.*, 2010). As explained in 3.2.2, self-directed learning is an approach used gradually more in adult education at tertiary institutions, and it can be defined in terms of the amount of accountability the students accept for their own learning. While self-directed students take control and manage their own learning, the non-self-directed student will seldom do so. The degree of self-control that students are willing to take will depend on their willingness, readiness, attitude, abilities and personal characteristics (Williamson, 2007; Cheng *et al.,* 2010). Establishing these characteristics can be done by means of an SDL readiness scale (Fisher & King, 2010). The results of such an instrument (SDL readiness scale) will allow educators to adapt, align and fine-tune their teaching efforts to best fit the group of students (Fisher *et al.*, 2001).

According to Cheng *et al.* (2010), there are currently five well-known, standardised self-directed readiness tests that can be used to establish students' willingness to study and work in a self-directed manner. These are the 1977 Guglielmino Self-directed learning readiness scale, the 1995 Deng Chinese version of Guglielmino's Self-directed learning readiness scale, the 1998 Ho Self-directed ability scale (in Chinese), the 2001 Fisher *et al*. Self-directed learning readiness scale and the 2007 Williamson Self-rating scale of self-directed learning. *The principles* of each of the five rating scales are outlined in Table 3.3.

Table 3:3: An overview of the SDL readiness rating instruments

Instrument	Characteristics	Date used
Guglielmino's self-directed learning readiness scale	**Consists of eight key components of SDL:** • self-concept of own ability to learn, • creativity and individuality in learning, • informed acceptance of accountability for own learning, • love of learning, • creativity, • positive orientation with regard to future learning, • ability to use basic study skills, and • problem-solving skills.	Guglielmino (1977)
Deng's Chinese version of the self-directed learning readiness scale	**Consists of five key components of SDL:** • love of learning, • learning motivation, • active learning, • independent learning, and • creative learning.	Cheng (2010)
Ho's Chinese Self-directed ability scale	**Consists of six key components of SDL:** • effective learning, • love of learning, • learning motivation, • active learning, • independent learning, and • creative learning.	Ho (1998)
Fisher *et al*. Self-directed learning readiness scale	**Consists of three key components of SDL:** • self-management, • desire to learn, and • self-control.	Fisher *et al.* (2001)
Williamson's Self-rating scale of self-directed learning	**Consists of five key components of SDL:** • awareness, • learning strategies, • learning activities, • evaluation, and • interpersonal skills.	Williamson (2007)

Source: Adapted from Cheng *et al.* (2010)

3.4.2 Assessment *of* learning

Assessment of learning involves assessment of students' learning activities in an SDL environment. This is not the same as assessing students' SDL abilities (see Section 3.4).

Self-directed learning can be enhanced by praxis such as appropriate assessment, blended learning, cognition and metacognition, cooperative learning as well as problem-based learning (Herrington *et al.*, 2014; Zohar & Barzilai, 2013). These are methods or strategies, and skills educators can use to assess SDL outcomes. For example, gathered evidence of learning performance (assessment) can be used to make informed decisions with regard to the next steps for instruction that are likely to be better, or better established than the decisions that would have been made in the absence of that evidence (Hayward, 2015).

According to Bacon and Stewart (2006) and Wynn-Williams *et al.* (2016), students can either have a *surface approach to learning* (rote learn) or *deep approach to learning* (engage with content) when learning, and for the enhancement of SDL skills a deep approach to learning is preferred in order to apply the knowledge in future. Surface learning is an old-fashioned method of memorising facts and not advantageous for the development of SDL or other forms of higher-order thinking, while deep learning may enhance lifelong learning, which is beneficial to SDL and higher-order thinking (Jarvis *et al.*, 2014). Assessment enhancing long-term and higher-order thinking is thus preferable in classes where SDL is promoted and fostered.

With a *deep approach to learning*, students learn by engaging with the subject content and by connecting concepts to previous knowledge, understanding and experiences (Wynn-Williams *et al.,* 2016). Moreover, concepts and skills learned on a deeper level are remembered longer than those learned on a surface level (Bacon & Stewart, 2006). From the literature, it is clear that the concepts of a deep approach to learning overlap with the concepts of self-directed learning, for example, higher-order thinking such as interaction with learning material, internal regulation of learning, self-learning, self-management, and lifelong learning.

Other pedagogical methods beneficial to SDL is a *flipped classroom* and *blended learning* (Jarvis *et al.*, 2014). A flipped classroom is where the traditional didactic lectures are replaced with activities rather than content, therefore becoming learning workshops rather than classes (Baeten *et al.,* 2010). *Blended learning,* is useful to enhance high-level learning skills, as it recognises the value of blending the best of the face-to-face learning experience with more traditional experiences (Alshahrani & Ward, 2014; Moskal *et al.*, 2013). An example is the use of an internet platform or web address where lecturers place information, resources, interesting facts, tests, assignments and/or chatrooms, for students to access as part of their study material to be used along with other learning materials during a course or module (Liu *et al.*, 2014; Mortera-Gutiérrez, 2006).

The principles of *cognition and metacognition* can be described with the words of Downing *et al.* (2009:610), who stated it is "thinking about thinking". They also emphasised that metacognition includes knowing how to reflect and consider thoughts, how to come to assumptions, and how to use what has been learned. To put this into perspective it means that, in order to solve problems effectively, students often need to understand how their own thoughts are generated, how they plan, monitor and evaluate tasks. Students need to reflect on how they perform important cognitive tasks such as knowledge retention and problem-solving (Garrison & Akyol, 2015). Therefore, problem-based learning may enhance essential metacognitive development in undergraduates to foster self-directed learning (Downing *et al.*, 2009). In this study students had to reflect on a weekly basis, on what they have learned with regard to the development of practical projects (see Addendum O).

According to Freeman *et al.* (2014), active learning such as *cooperative learning* could enhance student performance in Science, Engineering and Mathematics. In this study, there was an emphasis on active cooperative learning, as students were required to take an active part in their learning by working in small groups to accomplish a shared set of goals relating to the practical assignments. This, according to Johnson and Johnson (2009), may enhance self-directedness, as all group members were expected to add to the work of the group by sharing their thoughts, by contributing, by arguing intellectually, and by working towards a common goal. In order to guide students to develop SDL skills, educators should progressively scaffold the thinking of students by using cooperative interaction, the curricula, the teaching methods and an appropriate assessment strategy (Ashford-Rowe *et al.*, 2014; Meyers & Nulty, 2009).

When planning assessment, educators can:

- use authentic challenging assessments by connecting real-world experiences with students' content;
- test the knowledge and skills that students can demonstrate after a certain learning experience;
- assess the transfer of knowledge from known context to unknown; and
- assess the ability of metacognition by means of self-reflection or self-assessment (Ashford-Rowe *et al*., 2014).

3.5 Linking self-directed learning and problem-based learning

According to Havenga (2015), there are 12 basic principles or elements to be addressed by the lecturer in applying PBL in classrooms in order to enhance students' accountability and promote SDL. These are:

- **problem alignment and investigation** where students are asked to address the problem resulting from an ill-defined challenge as confirmed by Grant (2011);
- **student involvement** with regard to the active participation of a student in the learning practice as an enhancer of self-learning. This is supported by Pourshafie and Murray-Harvey (2013);
- **teamwork and communication** between team members to enhance interpersonal behaviour, interdependence, resolution-making and collective action as also found by Kozlowski *et al*. (2009);
- **students taking ownership** of their learning with regard to their commitment, accountability and internal motivation;
- **problem-solving skills** such as applying critical thinking and making informed decisions;
- **metacognition, reflection** and learning as confirmed by Breed (2010), which refers to learning management, monitoring and reflecting on project design and development;
- **organisation, arrangement and management** of the learning environment with regard to the management of learning time, resources and threats;
- **integration of learning technology** such as computers, cell phones, and e-learning platforms to enhance learning activities;

- **creation of knowledge** by integrating new and existing knowledge and understanding;
- **innovative creativity** – encouraging students to design an artefact or model, as confirmed by Bell (2010); and
- **assessment** with regard to self-assessment and peer assessment in order to establish learning progress and goal attainment.

In this intervention, a Mechanical Technology Automotive (MTA), hPBL model with seven steps, developed from the Maastricht and Aalborg PBL models, was used. This MTA model includes most of the aspects highlighted by Kaldi (2011) and Havenga (2015), and the steps thereof are outlined in Figures 7.2 and 7.3. Also see 2.4.1, 2.4.2 and Table 2.2.

hPBL as a teaching and learning strategy can be used as a **vehicle to foster SDL** (Amandu *et al.*, 2013). This also provides a link between SDL and PBL, as students worked in groups, collaborated with each other, assessed themselves and their peers, reflected on their work while developing projects and solving problems (English & Kitsantas, 2013).

3.6 Self-directed learning in Mechanical Technology

According to Du Toit-Brits (2018), individual students' self-directedness can be found in *five varieties of individual characteristics* (see Figures 3.1 and section 3.3.2), namely SDL talent, student motivation to learn, performance objectives, intrinsic and extrinsic objectives and self-awareness of own learning needs. By focusing on these five areas of individual characteristics educators should therefore be able to enhance students' self-directed learning in MT classes by creating appropriate opportunities. For example, the SDL ability of an individual refers to the capacity or inclination to be trustworthy, consistent, organised and goal orientated (Lee *et al.*, 2010). Students' motivation to learn in a self-directed manner arises from their ability to set learning goals, while their manner of setting performance objectives can be linked to their original reason for learning and their SDL ability (Du Toit-Brits, 2018).

In classrooms (including MT classrooms), educators should be able to understand and apply pedagogical content to enhance students' SDL by using activities and educational strategies focused on the improvement of the five individual characteristics. The need for developing specific pedagogical content knowledge (PCK) for Technology is confirmed by De Miranda (2017).

The importance of a self-directed lifelong learning ability can be illustrated with the following example. Technology knowledge has what is known as a half-life (the time for the knowledge to become obsolete). This implies that an MT teacher should learn, re-learn and construct new knowledge over the span of his or her career in order to keep up with the latest development in the field of MT. This is in line with the thinking of Arbesman (2013) and Guglielmino (2013).

To be successful in an academic environment and in a community that requires lifelong learning, the ability to self-regulate one's own learning is more important than it was before (Heikkilä *et al.*, 2012). As a result thereof, educational research has focused on self-regulated and self-directed learning and methods to advance it (Akareem & Hossain, 2016). The results of the above-mentioned research led to the question of what teachers can do to foster self-directed learning in their students.

Students also need to make *their own* significances while learning and this too can be directly linked to SDL, as the focus is on processes such as resourceful structure of knowledge, individual learning strategies, and evolving methods leading to self-directed learning (Tan *et al.*, 2009).

People are often confronted with the process of learning new knowledge and skills (Baartman & De Bruijn, 2011; Sidawi, 2009). This should also happen in MT classes where students are frequently challenged to master special skills and specialised applicable knowledge to bridge the gap between practice and theory e.g. different welding methods. Students then need to carry out actions such as setting learning goals, planning the next learning or working steps, selecting a suitable learning strategy, monitoring their progress and evaluating their learning performance against the learning outcomes (Stringer *et al.*, 2009).

In the South African curricula, the ability to "think for yourself", "study independently", be a "lifelong learner" and "work effectively in groups" (all skills related to self-directedness) (see Section 3.2.2) are seen as important skills to prepare individuals for becoming well-educated citizens equipped to apply knowledge and skills in ways that are meaningful to their own lives (DoE, 2011a:10). The CAPS document of the DBE (2011b) emphasises, in particular, objectives for subjects such as MT which may support the development of self-directed skills. These objectives require students to:

- identify and solve real life problems in their specific mechanical environment such as poor engine performace) e.g. fuel supply, weak electrical spark and worn valves);
- analyse, organise and evaluate critically (for example, find information with regard to solving a problem or finishing an MT artefact (e.g. compare the results of a compression test with the manufacturers specifications);
- make decisions by developing critical and creative thinking, [9](for example, how to improve a mechanical system);
- operate effectively as an individual and in a team (for example, how to do fault finding);
- organise and manage activities, for example what steps (in what order) to follow to make artefacts (for example, complete and build your own electrical system);
- take responsibility for activities (for example, ensure your own and your team mate's safety);
- collect information before starting a task (for example, what processes should you master in order to use certain equipment, manufacturers' specification for a specific engine);
- communicate effectively with team members to select the best decision;
- apply science and technology effectively to solve a problem or finish an artefact (for example, use available equipment and procedure to complete projects);
- display responsibilities with regard to the environment and the health of others (for example, getting rid of harmful gases when welding by using extractor fans);
- become lifelong learners (for example, master a basic skill such as fault finding in an engine);

Students find it challenging to learn autonomously, and at a recent conference the four key stages or steps were outlined as a guide for establishing self-directed independent teaching. These are: being ready to learn, setting learning goals, engagement in the

[9] Note: Examples in brackets apply to the MT discipline, as mentioned by researcher

learning phase and assessment of learning. This is confirmed by Fisher *et al.* (2001) and Cheng *et al.* (2010).

3.7 Conclusion

In this chapter, self-directed learning and related approaches were outlined. Further, the rationale for SDL was discussed and teaching and assessment for SDL were highlighted. Since PBL is a teaching-learning strategy that enhance SDL the implementation thereof in MT could have positive results regarding the teaching of pre-service teacher students. PBL application and the use of specific assessment methods should make a positive contribution to enhancing SDL in MT practical sessions.

In the next chapter, an overview of Mechanical Technology and essential knowledge and skills will be provided.

CHAPTER 4: MECHANICAL TECHNOLOGY: OVERVIEW AND DEVELOPMENT OF ESSENTIAL KNOWLEDGE AND SKILLS

4.1 Introduction

In this chapter, the nature, history, aims, requirements, and scope of [10]Technology, Mechanical Technology and Mechanical Technology Automotive (MTA) are outlined.

In South African schools, the Technology subjects are offered in three phases, namely the Intermediate Phase (Grades 4 to 6), the Senior Phase (Grades 7 to 9) and in the Further Education and Training (FET) Phase (Grades 10 to 12) (De Jager, 2011; DBE, 2011). In the Intermediate phase, Technology is offered as a component of the Natural Science curriculum. From Grade 7 to 9 (Senior Phase) it is offered as an independent subject, and from Grade 10 to 12 (FET), Technology divides into four separate independent subjects. These are Civil Technology, Engineering Graphics and Design (EGD), Electrical Technology and Mechanical Technology. Three of the four Technology subjects are also divided into three specialisation disciplines, Electrical Technology divides into Electrical Power Systems, Digital Electronics, and Electronics. Civil Technology divides into Woodworking, Construction and Civil Services, while Mechanical Technology divides into Automotive, Fitting and Machining and Welding and Metalwork (see Figure 4.1) (DBE, 2014a; 2014b; 2014c).

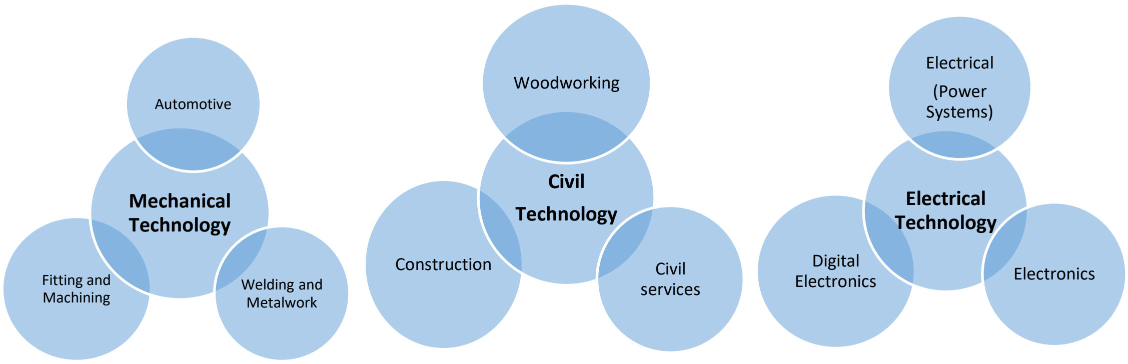

Figure 4:1: Technology subjects specialisation in FET phase
Source: Compiled by researcher

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[10] 'Technology' and 'technical' are used as synonyms to refer to any subject that includes content of a technical nature.

4.2 Conceptualisation and historical overview

Technology across the world mainly originated from subjects that were formally known as *Industrial arts, Technical* or *Technica* (Schatzberg, 2006). The discipline of Technology is relatively young (20-30 years) and different terms are globally used, namely Design and Technology, Technology Education and Technological Education (Ertmer *et al.*, 2012).

The word *'Mechanical'* in Mechanical Technology originated from and refers to the term 'manual labourer' as used in the late 14th century from the Latin and Greek words *mechanicus* and *mekhanikos* which denote to an engineer (Rihll, 2018). 'Mechanical' is also related to the words *mēkhanē* (device), Magh (to be able or to have power) (Harper, 2010). 'Mechanical' was also associated with an individual who "is employed in manual labour", "a handicraft worker", "an artisan", "a skilled workman" or "one making or repairing machinery" (Koniordos, 2018:32). With the arrival of the automobile, the word 'mechanic' became associated with an automotive technician as we know it today (Marx, 2010).

The word *'Technology'* in Mechanical Technology is derived from two Greek words, *techne* and *logos*. *Techne* means art, skill, craft, or the way, manner, or means by which something is gained and *Logos* refers to ways by which thought is expressed. Therefore, in reality, technology means dialogue about the way things are gained and made (Choudhury & Barman, 2014). In an educational context, Technology can be defined as "the use of knowledge, skills, values and resources to meet people's needs and wants by developing practical solutions to problems, taking social and environmental factors into consideration" (DoE, 2011:19).

According to the Curriculum and Assessment Policy Statement (CAPS) –

> [M]echanical Technology focuses on concepts and principles in the mechanical (motor, mining, shipping, rail, power generation) environment and on technological processes. It embraces practical skills and the application of scientific principles. This subject aims to create and improve the engineering and manufacturing environment to enhance the quality of life of the individual and society alike, and ensure the sustainable use of the natural environment and resources (DBE, 2014c:8).

The word ‘automotive’ is obtained by combining the words ‘auto’ (meaning ‘self’) and ‘motive’ (meaning ‘mobile’) to form the word *self-mobile* to describe any form of self-propelled vehicle (Stevenson, 2010). ‘The Automotive discipline’ (MTA) focuses on Mechanical Technology and encompasses petrol- and diesel-driven vehicles, motorcycles, lawnmowers and tractor mechanics” (DBE, 2014a:9).

The art of making things or using technology to improve human life as defined above can be traced back to about 10 million years ago when humans started making basic tools from stone, bones, wood, and antler (d’Errico *et al.*, 2012). Table 4.1 provides a brief timeline for Technology development adapted from Woodford (2008), and the development of technology and the accompanying industrial revolutions are shown in Table 4.2.

Table 4:1: A brief overview of technology

Timeline	Event or invention or discovery
± 10 million years ago	Basic tools from stone, wood, etc.
10 000 years before Christ (BC)	Boats are constructed
6000–7000 BC	Handmade bricks
4000 BC	Iron used for tools and weapons
3500 BC	Glass was first used
3500 BC	The wheel was invented
3000 BC	Copper and bronze were used
2500 BC	Papyrus used for writing documents
1000 BC	Beginning of the iron age
150–100 BC	Gears were used in clocks
50 BC	Vertical water wheels were developed
600 Christian Era (CE)	The wind force was used to drive windmills
18th century	Steam engines, internal combustion engines, chronometers, hot-air balloon, and iron bridges
19th century and 20th century	Batteries, steam locomotives, Stirling engines, generators, electric motors, propellers for ships, petrol and diesel engines, electric lamps, aeroplanes, air conditioning, cars, rechargeable batteries, television, space rockets, robots, computers and microprocessors and the World Wide Web.

Source: Adapted from Woodford (2008)

Table 4:2: Development of the industrial revolutions over the past centuries

Industrial revolution	**Example**	**Timeline**
First Industrial Revolution	"The single most important development in human history over the past three centuries". Important inventions of the time focused on the development of industries related to coal, iron, railroad, and textiles. Examples of these are the steam engine, factories, machines used in assembling, electric motors, generators, electric lights, the telephone, internal combustion engine and the vehicle.	± 1760–1880 (Stearns, 2018:3)
Second Industrial Revolution	This event was also called the *Technology Revolution* and witnessed the expansion and further development of industries related to electricity, diesel and petrol engines, petroleum and metal. Examples of these are better assembly lines, interchangeable components in machines, faster manufacturing processes, water supply, gas supply, sewerage systems, globalisation, aircraft, electrification, fertiliser and sophisticated weapons.	± 1870–1914 (Mokyr, 1998; Smelser, 2013)
Third Industrial Revolution	Also called the *Digital Revolution,* as the focus was on electronics. Where devices used to operate according to analogue, electric and digital electronic principles, the new revolution was digital electronics. Examples of these are computers, laptops, mainframe systems, electronic control systems such as alarms, remote controls, social media, CAN BUS systems in vehicles and microchips.	± 1950–2000 (Rifkin, 2012)
Fourth Industrial Revolution	This is the beginning of a new revolution (the fourth), the next great industrial revolution and nobody knows where it is going. Examples of these are generic editing and sequencing, artificial intelligence, robotics, big data, miniature sensors, 3D printing, smart cities and cyber-physical systems.	2018–unknown (Schwab, 2017; Collins & Halverson, 2018;)

Source: Compiled by researcher

4.3 The need for technology education in South Africa

Technology is an important part of every human being's daily existence. However, there is also an urgent shortage of artisans and technicians in South Africa, according to Breier and Erasmus (2009), and therefore people from abroad have been imported in an attempt to overcome the shortage of technicians and artisans. In another attempt to address the shortage of artisans and technicians, various training programmes have been set up over the last decade (Jones & Muller, 2016; Watkins & Ehst, 2008). However, the problem is still with us, and the shortage of artisans and technicians remains.

In order to advance general technology illiteracy, to address the shortages with regard to technical knowledge and the shortages of artisans and technicians, one should start by addressing the reality that basic technological literacy is needed at early stages of education (Dlamini, 2015; Watkins & Ehst, 2008). Technology literacy comprises knowledge, values and abilities (skills) to enable ordinary citizens to solve everyday technological problems and to sow the seed of technology interest at an early age (Collins & Halverson, 2018). The lack of some job opportunities will put a greater demand for workers currently employed and require more, different and more advanced skills of workers (Noe *et al.*, 2017). This further emphasises the need for technology training and a change in methodology and curriculum (Kalleberg, 2009; Rainie & Anderson, 2017). On 23 October 2017, the business report on the Independent Online (IOL) news and information website based in South Africa stated their concern with regard to the growing shortage of people in the field of Technology, from basic technicians to engineers (Nyatsumba, 2017). This concern was also mentioned earlier by the South African Democratic Teachers Union (SADTU) as confirmed by Chopra *et al.* (2009). These facts and concerns expressed by the press, emphasise the urgency of technology education in South Africa to as many learners as possible.

An awareness and understanding of technology, as well as well-planned teaching in technology, is essential in resolving the challenges explained above (Avalos, 2011). The first step in advancing technology, in general, should be the education of technology teachers. In this regard, education in South Africa went through many developmental phases because of a change in legislation and political issues (Marais, 2013). These developmental phases and political issues did not do technology in South Africa any good, as it resulted in a lack of growth in many areas including the technological field regarding well-trained technicians, artisans and technical teachers and lecturers (Botha & Rasool, 2011; Marais, 2013). Thus the shortage of technicians and the lack of general technological literacy can also be linked to a shortage of technology educators and change in educational legislation. For example:

- The government initiated various initiatives to address the above-mentioned challenges. They implemented Curriculum 2005 (C2005) in 2006 and later CAPS where all previous technical subjects were condensed into four (4) new subjects. As a result, only four technical subjects remained, technical schools had a surplus of technical teachers and principals, and departments of education had to redeploy these redundant teachers (Nemutandani, 2009). Consequently, some technical teachers had to teach subjects they were not trained for, some resigned and others were deployed at 'non-technical' schools (Segoe, 2012).

- In 2012 (after a seven-year gap), subject specialisation was reintroduced with nine subjects (see section 4.5) which is, according to the researcher, a positive initiative in addressing the shortages. This however also created a shortage (created by C2005) of technology teachers to fill the posts in the nine subjects (Marais, 2016).

This, in short, explains the current situation in South African schools with regard to technology education, and this is where the role of the NWU becomes clear. The NWU with its three campuses is currently the only institution (as far as could be established) offering technology education for all school phases for prospective technology teachers.

With regard to the training or education of technology teachers for the FET phase (the phase where MT is offered), the DBE (2014c) prefers that a teacher teaching MT or MTA in the FET phase should be a qualified technical teacher. The subject group Technology of the Faculty of Education at the North-West University (NWU) has been training technical teachers in all nine subjects of the Technology Curriculum since 2012 (NWU, 2018).

In the next section, a brief overview of technology practice outside of, as well as in South Africa will be provided.

4.4 Technology education outside of South Africa

This subsection briefly refers to other countries with regard to technology teacher education. Both developed and developing countries have been selected.

Different terms are used to describe technology education at school level in different parts of the world. In the **United States of America**, it is often referred to as Vocational and Technical Education (VTE), which is under the jurisdiction of the Carl D. Perkins

Vocational and Technical Education Act (Perkins, 2005). A technology teacher in the United States may have a Bachelor's Vocational Education degree or another suitable qualification (McDonald, 2011). The historical roots of Vocational and Technical Education (VTE) in the United States, also called Career and Technology Education (CTE), was based on the need for artisans and tradesmen during the late part of the nineteenth century. As a result, a number of private trade schools were developed (Hou, 2010; Wallerstein, 2011). Another pathway to a technical career in America was through apprenticeships (Gordon, 2014). Because of the third industrial revolution, the demand for trained artisans declined and the need for basic machine operators boomed. This, in the end, resulted in the partial collapse of some well-established apprenticeship programmes, and a new education and training system catering for basic machine operators was developed (Furtado, 2018). It is worth noting that in the United States, several state-operated Institutes of Technology are on equal accreditation with state universities (Jasanoff, 2011; Thelin & Gasman, 2003).

In **Australia**, technology or technical education is known as Australian Technical and Further Education (TAFE), which is under the management of the national government (Kangan, 1974; Misko, 2006; Smith, 2010). Government-owned institutes called Registered Training Organisations (ROTs), provided Vocational Education and Training (VET) courses allowing for certificates, diplomas, advanced diplomas and vocational graduate certificates (Elsner *et al.*, 2008; Karmel, 2008). A technology or vocational teacher in Australia would have completed his studies at a ROT and is known as a TAFE teacher or lecturer (Snodgrass, 2011).

Currently, the Technology Education programmes in Australia stand out in terms of ease of portability and flexibility regarding movement between vocational and higher education sectors, and they provide a stable, effective and well-organised learning system (Ainley *et al.*, 2008; Snodgrass, 2011).

Japan is a prosperous and technologically advanced country that also manufactures various technological products and makes a major contribution to the economy of the world (Castells, 2014). In the early nineties, the government adapted their national school curriculum to meet the demands of a modern world (Pomeranz, 2009). The emphasis was placed on computer literacy as well as Technology education offered at all lower secondary, upper secondary and tertiary institutions (Ananiadou & Claro, 2009). The

Japanese school structure is compiled with elementary school (six years), middle school (three years) and high school (three years), thus 12 years of which the first nine is compulsory (Wu, 2010). In the first nine school years of general education, technology is a required subject, and examples of the other subjects offered at higher school level are mechatronics, applied mechatronics, project studies, woodwork, electronics, food science and integrated problem-solving (Banks & Williams, 2013). Although the structure of this teaching model strongly supports the American system, Japan has become one of the most highly technologically acclaimed populations in the world. Even though technical education in Japan dates back to 1894, official Technology Education was implemented in 1958 (Murata & Stern, 1993; Ohara & Buchanan, 2018).

In **Ireland,** training with regard to trades, craftsmen and technical skills has a long history and Technical Education has been included in the school curricula since 1885 in an effort to provide for the demand for artisans (Lawson & Silver, 2013; Musgrave, 2013). Initially teaching of metalwork, woodwork and technical drawing was offered; however, in 1989 the subject Technology was officially implemented as it was considered a necessity for a growing economy (Leahy & Phelan, 2014). Currently, Technology is offered as an elective subject at secondary level (age 13–18 years). Technology subjects include material technology, construction studies, technical graphics, technical drawing, metalworking, engineering and general technology (Carty & Phelan, 2006; Lemonnier, 2013).

In **Nigeria** (a developing country), citizens have "historically considered Vocational Technical Education (VTE) as a program meant for low level, low brilliant and less privileged or second class citizens" (Comfort, 2012:2). This, however, is not the case anymore as Nigerians found that VTE could be a ticket to better qualifications, better economic growth, more employment opportunities and better protection against unemployment (Comfort, 2012).

Formal education in Nigeria started with the arrival of missionaries during the years of colonialism (1880 to 1890) and as a result, the first department of education was established in 1903 (Adyanga, 2011). Similar to other African countries, teaching of knowledge and skills has been conveyed in a complex, yet successful manner, from one generation to another. These skills include various traditional technical skills and crafts, and only after the independence of Nigeria in 1960, a large-scale attempt was launched to establish industries, infrastructure, agriculture, education (including technical education at school level) and training (Aladekomo, 2004; Garba, 2010).

Today Nigeria has a well-organised VTE programme as part of the Universal Basic Education (UBE) system also called the 9-3-4 system (Uwaifo & Uddin, 2009) where young people consider vocational education as a challenge and something worth doing (Uwaifo, 2010). This was achieved by means of an Educational Trust Fund (ETF) that was set up in 1993 to uplift VTE, and in 2006, this fund amounted to N5 billion Niara (Nigerian currency). The ETF was used, amongst others, to put workable policies in place, to advocate vocational education, to encourage continuity in VTE education and to put students on career paths. The 9-3-4 system comprises nine years of compulsory basic education followed by three years (non-compulsory) on the senior secondary level and four years (non-compulsory) on the tertiary level (Uwaifo & Uddin, 2009). Some of the subjects offered in VTE are Knowledge of Science, Technology, Engineering and Mathematics (STEM) as well as Electrical Technology (Ismail & Mohammed, 2015).

4.5 Technology education in South Africa

When the Cape of Good Hope was founded in 1652, several artisans and skilled immigrants from Europe, such as blacksmiths, bricklayers, clothes makers, winemakers, carpenters, stonecutters, boat builders and tanners settled with the Dutch founders (Groenewald, 2009; Pooley, 2009; Schutte, 2012; Worden, 2012). During the period 1652–1815, general teaching and training in vocational skills in South Africa developed in an effort to provide for the shortage of workers and this led to the first education act called the *Ordonnantie van de School Ordenen* which was drafted in 1714 (Heyning, 2017; Schutte, 2012). With the British occupation from 1815 to 1910, about 5,000 people of British origin, many of whom were trained in various skills, settled in South Africa (Laband, 2010). Formal education was later provided with the founding of some industrial schools in the Cape, such as the Ottery School of Industries providing training for blacksmiths, farmers, cabinetmakers, stonecutters, bricklayers and similar skills that were in demand at that time (Larey, 2012). Other forms of structured Technical Education were implemented by the Natal Government Railways in 1884 and this was followed by the establishment of the Durban Technical College and institutions in Pretoria and Johannesburg under the control of Professor John Orr (Badroodien, 2004; Erasmus, 2008; Vally & Spreen, 2014). Thereafter, technical and vocational training in South Africa gained momentum and many schools, colleges and other training institutions such as TVET colleges, Universities of Technology and universities evolved under the legislation of the government (Ball, 2017; Bowen *et al.*, 2016).

However, after the first democratic election in 1994 changes involved the phasing out of Technical Education and the implementation of a new Technology curriculum (Freeman *et al.,* 2014). The subject *Technology,* announced on February 1997 by the Minister of Education, was introduced as part of the Curriculum 2000 campaign, aiming at resolving curriculum backlogs of the past and keeping up with international trends with regard to Technical Education (Benade *et al.*, 2010; DoE, 1997; Heymans, 2007; Jansen, 2002; Vambe, 2005). However, due to some changes, Curriculum 2005, known as the National Curriculum Statement (NCS), was developed and implemented (Chisholm, 2003). Curriculum 2005 was based on Outcome Based Education (OBE) and during the next few years OBE did not fully perform as was intended. In 2010, the Curriculum and Assessment Policy Statement (CAPS) was introduced as an amendment to the original NCS documents (Du Plessis, 2013; Heymans, 2007). The CAPS and NCS documents provide for Technology in three school phases, namely (section 4.1):

- Intermediate Phase: Grades 4–6 (part of the Natural Science curriculum).
- Senior Phase: Grades 7–9, and
- Further Education and Training Phase (FET): Grades 10–12 (see Section 4.1).

However, this curriculum did not allow for specialisation in the different Technology disciplines, namely Electrical, Civil and Mechanical study fields in the FET phase and at the end of 2010, the CAPS was amended to allow for specialisation in the different disciplines. The amendments came into effect on January 2012 in Grade 10, which was aligned with the phasing out of Technology as a stand-alone subject in the Intermediate Phase, as Technology was included in the Natural Science curriculum (DBE, 2014c). During 2012 and 2013, the initial problems with the CAPS specialisation were addressed and in January 2014, the final CAPS (specialisation) documents were introduced.

4.5.1 General aims of Mechanical Technology in South African (FET phase)

Over and above the general aims of the South African curriculum, Mechanical Technology (MT) as implemented in 2014 provides embedded knowledge regarding specific

Automotive, Welding and Metalwork, and Fitting and Machining content. These school subjects serve the purpose to ’equip learners, irrespective of their socio-economic background, race, gender, physical ability or intellectual ability, with the knowledge, skills, and values necessary for self-fulfilment and meaningful participation in society as citizens of a free country’ (DBE, 2014c). The structure and content of Technology subjects in the FET phase provide knowledge for access to some higher educational facilities such as TVET colleges, for the transition of learners or students from educational institutions to the workplace and for proof of evidence to employers regarding the profile of a learner’s competences (DBE, 2014c:8–16).

MT, in general, focuses on, amongst others, safety, tools and equipment, materials, terminology, forces, maintenance, systems and control, gears, belts, pulleys, transmissions, levers, hydraulics, pneumatics, direct current (DC) electrics, engines, pumps, and turbines.

The subject MT aims to develop students or future workers that are able to: “identify and solve problems, make decisions using critical and creative thinking and work effectively as individuals and with others as members of a team” (DBE, 2014c:6).

MT also aims –

> *[To] equip learners to organise and manage themselves and their activities responsibly and effectively, to collect, analyse, organise and critically evaluate information and to communicate effectively using visual, symbolic and/or language skills in various modes. In addition, learners should be able to use science and technology effectively and critically showing responsibility towards the environment and the health of others, and demonstrate an understanding of the world as a set of related systems by recognising that problem-solving contexts do not exist in isolation (DBE, 2014c:8).*

4.5.2 Specific aims for Mechanical Technology (Automotive) in South Africa (FET phase)

Although the original 2012 Mechanical Technology subject included an automotive component in the curriculum, it was only with the implementation of the CAPS specialisation in 2014 that MTA was introduced as an individual subject in the Grade 10–12 curriculum (Stumpf & Niebuhr, 2012).

In the Automotive component, learners are educated and instructed in industry-related automotive matters. Some of the topics addressed in MTA are shown in Table 4.3.

Table 4:3: Shortened list of topics addressed in MTA (DBE, 2014c)

Link with industry	Topics		Curriculum link with industry	Topics
Safety	• OHS act • Hand tools • Pedestal drill • Bench grinder • Lathe • Milling machine • Guillotine • Compressors • Fire extinguishing equipment • Bending machines • Jacks, trestles and lifts • HIV/AIDS awareness • Welding equipment • Presses • Hydraulic equipment		**Engines, pumps, and turbines**	• 2-stroke and 4-stroke engines • Engine cycles • Drivetrain layouts • Valve arrangements • Valve timing diagrams • Crankshaft balancing • Crankshaft arrangements • Firing order • Turbochargers • Engine components • Engine CANBUS systems • Petrol and diesel engines • Steam engines • Vehicle electrics

Link with industry	Topics		Curriculum link with industry	Topics
Tools and equipment	• Spanners • Pliers • Allen keys • Stocks and dies • Compressor tester • Cylinder leakage tester • Gas and electronic scanners • Wheel balancer • Wheel alignment		Systems and control	• Carburettors • Master and slave cylinders • Brake systems • Properties of oil • Preventative maintenance • Cooling systems • Fuel injection systems • Alternator systems • Lubricating systems • Differential systems
Forces	• Moments • Stress • Frames • Modules of elasticity • Power work		Maintenance	• Gear drives • Belt drives • Chain drives • Oil • Friction

The MTA and MT learners in South African schools are required to take part in practical sessions in an effort to bring theory and practice together, and therefore practical sessions are included in the education of students at the NWU. During the practical sessions, all students need to complete various tasks, Practical Assessment Tasks (PATs), master specific skills, learn how to use the equipment and apply safety measures (Benade, 2017; DBE, 2014c).

4.5.3 Requirements for Mechanical Technology teachers in the FET phase in South Africa

The Department of Basic Education (DBE) requires that an MT teacher should have industry-related experience, workshop management skills and a tertiary technical teacher qualification (DBE, 2014c). However, finding teachers meeting all three of these requirements is difficult. Therefore, the North-West University (NWU) subject group Technology attempts to provide opportunities for a student to develop and gain experience regarding all three requirements.

Automotive Technology modules VTEE-222 and 312 for teacher students are core, eight credit, second- and third-year subjects offered to students enrolled for the BEd Mechanical Technology programme. VTEE 222 is a compulsory second semester module offered in the second year, while VTEE 312 is offered in the first semester of the third year. The Mechanical component of the curriculum offered at the NWU consists of two focus areas, namely Automotive and Fitting and Machining. The two MT focus areas consist of thirteen modules totalling 108 credits out of a total of 527 in the program. Thus of the 527 credits for the degree, 108 credits are MT credits. The Automotive focus on which this study is centred includes generic and specialisation topics. Examples of generic topics are safety, tools, materials, joining methods and forces, while examples of specialisation topics are terminology, maintenance, systems and control, and engines.

The NWU has well-equipped MT workshops where industry-related experience, practical skills and workshop management skills can be applied. Furthermore, the DBE also requires an MT teacher to teach with confidence, interact with learners, plan practical work, plan theory lessons, provide for safety, be innovative and keep self-motivation (DBE, 2014c).

Graduating students at the NWU are required to (see Addendum N):

- demonstrate, apply and correctly evaluate integrated subject knowledge and understanding of subject-related terms;
- demonstrate concepts, facts, phenomena and rules that specifically apply to the context of the Mechanical Technology subject;
- demonstrate knowledge of the interpretation and implementation of the school curriculum and the effective implementation of subject-specific curriculum requirements, such as organising classroom activities;
- display a positive work ethic and appropriate behaviour that benefits, enhances and develops the teaching profession and contributes to effectively teach Mechanical Technology while promoting acceptable social values and principles; and

- demonstrate the ability to assess learners in reliable and varied ways and to utilise the assessment results to improve their teaching of Mechanical Technology presented at university level.

The outcomes in the faculty yearbook reflect the general didactical skills required from an educator in the FET phase. These are:

- equip students, irrespective of their socio-economic background, race, gender, physical ability or intellectual ability, with the knowledge, skills and values necessary for self-fulfilment, and meaningful participation in society as citizens of a free country; and

- provide access to higher education; facilitating the transition of students from educational institutions to the workplace; and providing employers with a sufficient profile of students' competencies.

4.6 Mechanical Technology Automotive (MTA) knowledge, competencies and skills

The development of knowledge, competencies and skills (knowledge and understanding) should be the aim of any educational institution. Plato was one of the first scholars to define *knowledge*. He defined "knowledge to be true belief plus something more – an account that justifies or warrants the belief" (Cornford, 2013:13). Contandriopoulos (2010) and his co-workers describe knowledge in two vital practices, namely '*individual,* that is, held in people's heads and translated (or not) into action by human will and agency, and *collective*, that is, socially shared and organisationally embedded, whose effect on individual behaviour and the specific outcomes is more diffuse' (Greenhalgh, 2010). Knowledge is thus beliefs or perceived realities in an individual's or group of people's minds that may or may not lead to action.

Skills or more specific, *technical skills,* entail, according to Katz (2009), an understanding of, and ability in, a specific type of activity that requires methods, procedures and/or techniques to execute. For example, it is simple to visualise the specific *technical skills* of a surgeon, a tennis player or a welder, while visualising those of a psychologist or an attorney is not as simple. Technical skills thus involve specialised knowledge and systematic abilities within a specialty knowledge area, for example, the skills and expertise allowing one to use the tools and techniques of the specific discipline. 'Employability' and 'work-readiness' are words often found when reviewing the literature with regard to the skills, knowledge, attitudes and commercial understanding. These are skills that will enable new graduates to make productive contributions to organisations, and this is what employability entails (Mason *et al.*, 2009).

Competent is generally defined as “consisting of integrated pieces of knowledge, skills and attitudes and is assumed to be a prerequisite for educating function of a profession” (Baartman & De Bruijn, 2011:126). Although knowledge, skills and competence are related, they are not the same (Asheim *et al.*, 2011). For example, an individual may be skilled (trained) to operate a lathe, but he or she may not be competent to do so (due to a ‘rusted’ brain or unfamiliarity with regard to another make of lathe or even a temporary health issue). Another way of explaining this is that an individual could pose knowledge with regard to some ability but do not possess the skills needed to put the knowledge into action, thus rendering him or her incompetent. The knowledge plus the skills to use the knowledge, becomes the competency. Not being competent could also result from an individual who could read and watch videos showing them how to weld and thus possess the knowledge, but they also need to practise (learn the skill) with a real welder and be assessed before being competent to weld.

When educating and preparing students for the technology MT and MTA environment, the ‘learning or competency’ differs from ‘learning or competency’ in an academic environment, as in a technology workshop the focus is on real industrial professional (technology-related) tasks aiming at the development of specific competencies, and social practice (Fry *et al.*, 2009).

With regard to **skills and competency**, Mechanical Technology teachers should be able to use various machines, equipment, and tools with confidence, safety and the needed dexterity (DBE, 2014c). These include ‘skills to use’ general and specialised equipment such as (in no specific order) a milling machine, lathe, callipers, micrometres, safety equipment, dial gauges, height gauge, profile cutters, instruments, test equipment, arc welders, CO_2 welders and tungsten inert gas (TIG) welders. Other machines are CO_2 testers, metal inert gas (MIG) welders, plasma cutters, wheel aligners, wheel balancers, torque wrenches, socket spanners, spanners, special tools, timing lights, valve cutter and feeler gauge (Kett, 2012). Students should also be able to make adjustments, measure values, remove and replace components, fine-tune and weld.

The *class atmosphere* in a technology centre also differs from the *atmosphere* of an academic class in that students and teachers sometimes work in *dangerous* conditions with regard to heavy machines and they are often more intimately involved with one another because the student or educator ratio is much lower.

4.6.1 Models or frameworks for the learning of Mechanical Technology (MT) or MTA knowledge and skills

Two taxonomies of intellectual competencies are discussed below.

4.6.1.1 Bloom's taxonomy

As was originally identified by Bloom in 1956, various intellectual competencies can be categorised in six different levels of Bloom's taxonomy (Bloom, 1956). Since 1956, Bloom's taxonomy evolved and six levels are distinguished (Gluga *et al.*, 2012; Forehand, 2010). The six levels are shown below with examples of the application thereof in MT in brackets:

- Level 1. **Remember**, recall and recognise (name the properties of a metal material);
- Level 2. **Understand**, comprehend, translate and interpret (explain the use of multigrade oil in modern internal combustion engines);
- Level 3. **Apply**, knowing when and why to apply knowledge (make a selection of suitable materials to be used in a specific artefact such as choosing a material suited to fabricate a stub axle);
- Level 4. **Analyse,** seeing the relationship between ideas or theories (analyse and review the use of oil as a suitable lubricant for internal combustion engines);
- Level 5. **Evaluate,** judging against criteria (recommend suitable joining methods to be used on stainless steel or evaluate the results of using diesel fuel in a petrol engine); and
- Level 6. **Create,** combine, form a hypothesis or find an alternative (develop a set of steps to follow to complete a complex artefact).

Remembering involves the ability to retrieve, recognise and recall prior knowledge. *Understanding* refers to the capacity to construct understanding from oral, written or visual inputs, while *applying* denotes to carry out or to do something by implementing existing knowledge. *Analysing* involves the ability to break (knowledge) down into components in order to examine it in detail. *Evaluating* is the cognitive ability to make a judgement based on criteria, and *creating* is the skill to put cognitive elements together to form a functional whole (Forehand, 2010; Ozola, 2014). In Table 4.4, the application of Bloom's taxonomy in Technology, MT and MTA with regard to competencies and skills are shown.

Table 4:4: Bloom's taxonomy in action

Level	Keywords	MTA application
1	**Remembering** and memorising knowledge by means of observation, imitation, and practice.	Specific hand skills such as adjustment of brakes, setting the ignition timing, dismantling procedure, etc.
2	**Understanding** and knowing to apply and interpret knowledge	Specific safety measures of MTA and tools. Apply safety measures when using heavy lifting equipment after assessing and interpreting the possible dangers.
3	**Application** and use of technological principles, rules or recipes.	The knowledge of a technician making diagnoses with regard to an engine running too rich. Apply and use prior knowledge of the fuel supply system, knowing which sensors to scan.
4	**Analyse** and generalise skills used in the broad use of technology.	The knowledge of a technician making diagnoses with regard to an engine not starting. Reading the OBD codes and making assumptions thereof.
5	**Evaluate** judge against criteria. Knowledge that enables a person to know what to do, when and how to do it.	The knowledge a technician uses when deciding why a clutch is not engaging. Judge the problem against known criteria with regard to clutch failure. Evaluate the situation and decide what to test first and what to remove for inspection.
6	**Create** and make a synthesis. Skills enclose tacit technological or scientific theories such as the use of gravity and friction	Interpret a torque diagram with regard to engine r/min and stroke length and the implications of fitting a camshaft with a larger duration.

Source: Adapted from the work of Mehaut and Winch (2012) and Gambin *et al.* (2012).

Figure 4.2 was added to compare Bloom's initial and amended taxonomy.

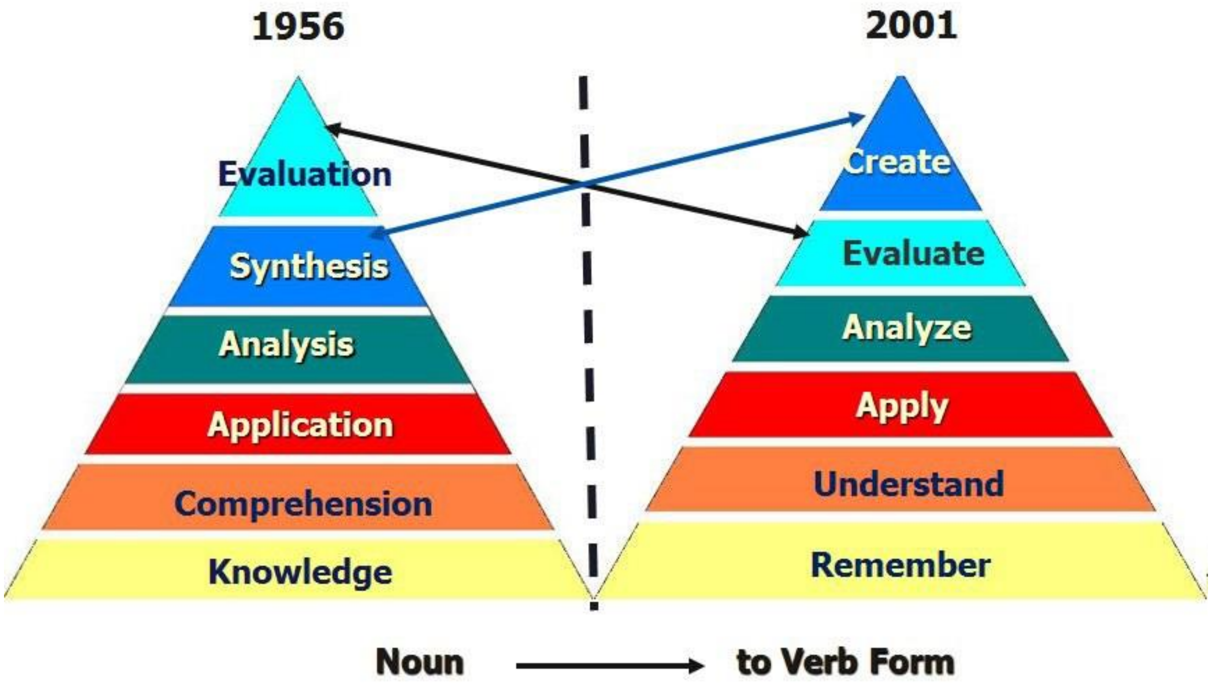


Figure 4:2: Bloom taxonomy "old vs new"

Although, according to Seaman (2011), Bloom's taxonomy is well known and used by many institutions, there are other taxonomies worth considering and therefore a brief look at Marzano's taxonomy.

4.6.1.2 Marzano categories of knowledge

Marzano, according to Karadag & Kaya (2017) identified three categories or levels in which all knowledge and understanding could be classified. This knowledge system is known as Marzano's taxonomy, and he described the different levels as follows:

- Level one – *the cognitive system* comprises knowledge retrieval, comprehension, analysis and utilisation of knowledge;
- Level two – *the metacognitive system* involves specific learning goals, monitoring of learning and quality of the learning; and
- Level three – *the self-system* of the students' beliefs, motivation, emotions, efficiency, and importance of the learning to him or her (Karadag & Kaya, 2017).

Although Marzano identified only three levels of knowledge, he identified five dimensions of thinking that learners go through when teaching (Heong *et al.,* 2011; Al Rowais, 2019).

This idea of him evolved into a five-step model or plan that can be used by educators to enhance learning. These are outlined in Table 4.5.

Table 4:5: Marzano's dimensions of the learning model in action

Step	Keywords	Application
1	Positive attitudes and perceptions about learning	Motivate students by making them interested in MTA, e.g. feel safe and comfortable in the workshop.
2	Acquisition and integration of knowledge	Assist students to relate to new and prior learning, organise new knowledge in meaningful ways and make it part of long-term memory.
3	Extension and refinement of knowledge	Students should extend and refine the knowledge acquired in step 2 by making more connections with prior and future work to refine their knowledge.
4	Meaningful use of knowledge	This aids decision-making, investigations, experiments problem-solving, reasoning and analyses.
5	Productive habits of mind	This shapes behaviour including planning, critical thinking, creative thinking and innovation.

Source: Adapted from Al Rowais (2019)

4.7 General workshop knowledge and skills needed in MTA

Although there are various similarities and differences between the taxonomies of Marzano and that of Bloom, such as comprehension, analyses, utilisation of knowledge, motivation, etc. (see Table 4.4), Bloom's taxonomy with more level descriptors allows the researcher to better relate, describe and summarise knowledge and skills associated with the MTA workshop.

Both knowledge and skills are essential in the practical workshop. An example of this is the skills to test a conventional ignition system with no knowledge of what will happen if the same test procedure is used on electronic ignition.

Various knowledge and skills needed in workshops are intertwined in many ways with regard to eye–hand coordination and body movement or placement, it is difficult to describe skills apart from knowledge; therefore, the researcher refers to practical competencies. The list of competencies can be summarised into three domains, namely:

- *General technology* practical competencies for MTA and related technical subjects. For example, before a student can learn how to use a spanner, he or she should know that there are different types of spanners used for different job applications and there are basic safety rules to adhere to when using a spanner (never push a spanner rather pull it to prevent injuring hands) (Benade *et al.*, 2010; Canada, 2015).

- *Specific technology* competencies for MTA (know how to use subject-specific tools such as gas analyser, radiator tester, etc.). The use of a welder is an example of this as most mechanical workshops will often use welding equipment, however a civil workshop will have few uses for it. The user should then (before using it) have some understanding and prior knowledge of the properties of materials, the type of welding rod needed, the ampere setting needed for the thickness of the material and the relationship between the dimensions of the material and the ampere setting. The user also needs to be aware of the electrical hazard, the heat danger and the risk of ultraviolet radiation (Althouse *et al.*, 2004; Benade *et al.*, 2010).

- *Specialised technology* competencies (use specialised equipment such as an OBD scanner on a specific model of vehicle). These technology competencies refer to the use of specialised subject-specific components used in specialisation. Another example of this is the CNC milling machine and lathe. The user of these machines needs to be well trained in mathematics, programming and operational skills before attempting any machining. He or she should also be knowledgeable with regard to safety and three-dimensional processing and should have a thorough knowledge of the operation of a lathe or mill (Benade *et al.*, 2010; Hector, 2012).

4.8 Specific knowledge and skills needed for teaching

There are various skills, knowledge, ability and competencies needed by MTA teachers enabling them to teach. These are according to Benade (2016; 2017), the DBE (2014c), Elder *et al.* (2013), Greene and Yu (2016), Maslow (2013), NWU (2018) and Voogt *et al.* (2013) in terms of knowledge and understanding regarding –

- teaching the subject with self-confidence (knowledge with regard to study methods, learning strategies, learning styles, curriculum development, Bloom's taxonomy, and general classroom management;

- fault tracking (knowledge about test procedures, test methods, and operation of test equipment to analyse and fix a mechanical problem in an engine, machine, gearbox or charging system);

- emotional intelligence (to intermingle with learners in a friendly manner, without creating familiarity, relieve conflict and keep discipline);
- workshop and equipment management, safety, teaching environment, and budget (check equipment, do stock taking, calculate quantities for projects, apply safety, maintain a safe work environment, keep records and compile a budget);
- planning practical and theoretical sessions (make sketches and scale drawings of future projects, plan the steps and processes needed to complete a project, manage time, prepare lessons and keep academic records);
- maintaining and servicing workshop, tools, equipment and instruments (do regular preventative servicing to machines, clean equipment, sharpen cutters, etc.);
- technological pedagogical content knowledge (PCK) (a combination of content knowledge and pedagogical knowledge e.g. what teaching method and what teaching aids to use when explaining gear ratios); and
- deciding on different types of assessment, e.g. self-assessment and peer assessment (assessment of learners' work, skills and competencies).

4.9 Educating Mechanical Technology teachers at the North-West University

As far as could be established, the NWU with its three campuses is one of a few institutions offering education for prospective Technical or Technology teachers in all the FET subjects. A bachelor's (BEd) degree is issued after 527 credits have been obtained on NQF level seven. Adhering to all the requirements and meeting all the stipulations in the Minimum Requirements for Teacher Education Qualifications (as revised in 2018) the NWU offers various courses (see Table 4.6) for prospective Technology teachers. These are:

- BEd Senior and Further Education and Training phase: Engineering Graphics and Design for Education: 4BN-J16;
- BEd Senior and Further Education and Training phase: Mechanical Technology: 4BN-J17;
- BEd Senior and Further Education and Training phase: Civil Technology: 4BN-J18; and
- BEd Senior and Further Education and Training phase: Electrical Technology Education: 4BN-J19 (see Addendum N).

The Mechanical Technology Education curriculum, is compiled using 14 modules. Modules consist of 8, 12 or 16 credits, (depending on amount of content). This means that 108 credits or 1080 hours are spent on the Mechanical component of the BEd programme (University, 2018). The MT program with the different modules and credits are shown in Tables 4.6 (NWU, 2019).

Note: Modules ITEE, VTEE, FETM and FETW are all mechanical modules.

Table 4:6: BEd programme for Mechanical Technology

EDU.3.5.27 **BEd Senior and Further Education and Training phase: Mechanical Technology Education / BEd *Senior en Verdere Onderwys en Opleidingsfase: Meganiese Tegnologie vir onderwys***

CODE AND DELIVERY MODE: 4BN-J17 (Contact) **PC** (Afrikaans, English)

KODE EN METODE VAN AFLEWERING: *4BN-J17 (Kontak)* ***PK*** *(Afrikaans, Engels)*

YEAR LEVEL 1 / *JAARVLAK 1*			**YEAR LEVEL 2 / *JAARVLAK 2***			**YEAR LEVEL 3 / *JAARVLAK 3***			**YEAR LEVEL 4 / *JAARVLAK 4***		
Module code ***Modulekode***	**Cr** ***Kr***	**Type** ***Tipe***	**Module code** ***Modulekode***	**Cr** ***Kr***	**Type** ***Tipe***	**Module code** ***Modulekode***	**Cr** ***Kr***	**Type** ***Tipe***	**Module code** ***Modulekode***	**Cr** ***Kr***	**Type** ***Tipe***
FIRST SEMESTER / *EERSTE SEMESTER*											
Fundamental modules *Fundamentele modules*			Fundamental modules *Fundamentele modules*			Fundamental modules *Fundamentele modules*			Fundamental modules *Fundamentele modules*		
EDCC114	8	H	EDCC214	8	H				EDCC413	8	H
EDCC115	8	H	EDCC215	8	H	EDCC315	8	H	EDCC414	8	H
EDCC118	8	H	EDCC218	8	H	EDCC318	8	H	EDCC418	8	H
			ENAC211	8	X	EDTM312	8	X	RESF412	8	X
						WVOS312	12	X			
			Specialisation Subject 1 *Spesialiseringsvak 1*			Specialisation Subject 1 *Spesialiseringsvak 1*			Specialisation Subject 1 *Spesialiseringsvak 1*		
			FETW211	**12**	**H**	**ITEE312**	**8**	**H**	**ITEE413**	**8**	**H**
						VTEE313	**8**	**H**	**VTEE413**	**8**	**H**
Specialisation subject 2 [and GET subject] *Spesialiseringsvak 2 [en AOO vak]*			Specialisation subject 2 [and GET subject] *Spesialiseringsvak 2 [en AOO vak]*			Specialisation subject 2 *Spesialiseringsvak 2*			Specialisation subject 2 *Spesialiseringsvak 2*		
EGDE113	12	H	EGDE212	12	H	EGDE312	16	H	EGDE411	16	H
FETC111	12	H	WSKT213	8	H						
FETM111	8	H									
FETP111	8	H									
Total 1st semester *Totaal 1ste semester*		64	Total 1st semester *Totaal 1ste semester*		64	Total 1st semester *Totaal 1ste semester*		68	Total 1st semester *Totaal 1ste semester*		64
SECOND SEMESTER / *TWEEDE SEMESTER*											
Fundamental modules *Fundamentele modules*			Fundamental modules *Fundamentele modules*			Fundamental modules *Fundamentele modules*			Fundamental modules *Fundamentele modules*		
EDCC125	8	H	EDCC224	8	H	EDCC323	16	H	EDCC423	8	H
						EDCC325	8	H			
EDCC128	8	H	EDCC228	8	H	EDCC328	8	H	EDCC428	8	H
Choose one *Kies een* ALDA122 / ALDE122	12	X	WVOS222	12	X				RESF422	8	X
Choose one *Kies een* AFCL121[1] / PECL121[2] / SECL121[2] / SOLC121[2] / ZUCL121[2]	8	X	ENAC221	8	X				LOCC421	1	X
									LOLT424	1	X
									Choose one *Kies een* LTSF420 / LTSF421 / LTSF422 / LTSF423 / LTSF424 / LTSF425 / LTSF426 / LTSF427 / LTSF428 / LTSF429	1	X
			Specialisation Subject 1 *Spesialiseringsvak 1*			Specialisation Subject 1 *Spesialiseringsvak 1*			Specialisation Subject 1 *Spesialiseringsvak 1*		
			ITEE222	**8**	**H**	**ITEE323**	**8**	**H**	**ITEE423**	**8**	**H**
			VTEE223	**8**	**H**	**VTEE323**	**8**	**H**	**VTEE423**	**8**	**H**
Specialisation subject 2 [and GET subject] *Spesialiseringsvak 2 [en AOO vak]*			Specialisation subject 2 *Spesialiseringsvak 2*			Specialisation subject 2 *Spesialiseringsvak 2*			Specialisation subject 2 *Spesialiseringsvak 2*		
EGDE123	12	H	EGDE222	16	H	EGDE322	16	H	EGDE421	16	H
FETE121	12	H									
FETM121	8	H									
WSKT122	8	H									
Total 2nd semester *Totaal 2de semester*		76	Total 2nd semester *Totaal 2de semester*		68	Total 2nd semester *Totaal 2de semester*		64	Total 2nd semester *Totaal 2de semester*		59
Total Year level 1 *Totaal Jaarvlak 1*		140	Total Year level 2 *Totaal Jaarvlak 2*		132	Total Year level 3 *Totaal Jaarvlak 3*		132	Total Year level 4 *Totaal Jaarvlak 4*		123
TOTAL FOR THE PROGRAMME / *TOTAAL VIR DIE PROGRAM*											527

In an effort to fulfil the requirements set by the DBE (as the employer) with regard to MTA teachers, the NWU aims to meet specific levels of skills and practical competencies during their four years of educating MTA students (see 4.5.3). No practical classes are offered during the first year, however from the second year students need to attend practical as well as theoretical sessions once a week for a period of 12 weeks per semester with a time allocation of 4 to 5 hours per week (depending on credits). This implies that all students gain about 48 to 60 hours of MT related experience. The workshop activities are aiming at complementing theory with practice and are planned in such a way that they include various tasks, Practical Assessment Tasks (PATs), specific skills, use of equipment, and application of safety measures (see Table 4.3). Logistical, legal and other constraints in a workshop at a university have its limitations with regard to availability of components, working hours, lack of customers, to name a few, and therefore sections of the work are simulated in order to gain experience. Other sections such as the completion of PATS are more aligned (in terms of skills required) to work within the industry.

Mechanical Technology Automotive (MTA) also includes mechanical entities, Mathematics, Physical Science, Engineering Graphics and Design, applied science, Trigonometry, Newton's laws, chemical equations, techniques, and Chemistry.

4.10 Shortcomings of the education of Mechanical Technology students at the NWU

Some of the problems encountered with regard to in-service education of MT or MTA students are:

- There is no clear guidance (from official documents and literature) concerning the education of MT teachers with regard to practical competencies and the fact that some students experience challenges such as low motivation, lack of interest and inability to work in a team;
- Practical sessions are relatively short (± 2,5 hours) and therefore practical work sometimes has to rely on simulated workshop conditions, and as a result of the constant upgrading of technology that is applied in machines, cars, gearboxes, etc., the latest examples of these are not always available to work with; and
- Lack of funding is another shortcoming, as new equipment is very expensive and sometimes hard to find.

Although current pre-service teachers should be able to adapt to change in future curriculums, teaching methodology, practical skills and policy, it is essential to equip them with the latest and best knowledge, skills and relevant abilities to cope with such demands. It was with this industry-related experience and workshop management skills in mind that the objectives of this study were formulated.

4.11 Selecting appropriate problems for Mechanical Technology

Although the selection of problems, in general, was discussed in Chapter 2, the specific problems selected for this intervention are discussed briefly. Beyond the frameworks of Bloom and Marzano there are five important aspects of selecting suitable PBL projects to adhere to. These are the level, complexity, structuredness, relevance and type of problem (see Section 2.3.2 to 2.8). To meet the guidelines provided in Figure 2.2 with regard to:

- Level of the problem. The projects selected in 2017 and 2018 (see addendums F and J) met the criteria of Bloom's levels one to six. For example, students had to select suitable scales, materials and methods to develop their wire cars, and they had to understand the basic layout of an automotive wiring system and the operation of basic electrical switchgear.

- Complexity of the problem, referring to the higher levels of Bloom's taxonomy, were met as the projects required students to apply and use technological principles, rules and methods to complete the projects. There was an allowance for progress and scaffolding from the project 1 to project 2 in 2017, the competencies needed to solve projects three and four were on a higher level and the lecturer provided a smaller amount of support (less scaffolding) (see Chapter 5).

- The structuredness of the problem. The four projects selected for the two interventions were ill-defined and thereby met the criteria set by Greiff *et al.* (2014) (see Section 2.3.2). The projects can be described as ill-defined, as just enough information with regard to the projects was provided. For example, the problems started with phrases such as 'design your own', 'build your own' and 'make a replica of'.

- The relevance of the projects. All four projects were relevant to the MTA subject as the content thereof aligns with the outcomes in the study guides (see Table 4.3). For example, the auto electrical systems, materials and joining methods are in the module outcomes and curriculum.

- The fitness of the projects. All four projects were fitting regarding the type of problem as they align with the curriculum content of MTA (see Table 4.3). For example welding, bending, soldering, joining, and connecting.

4.12 Conclusion

Chapter 4 provided a brief history of technology in South Africa and in other countries. The chapter also elaborated on the aims of MT, the education of MT teachers, as well as the use of PBL in MT classes. The importance of technology knowledge, skills and competencies were outlined as well as the importance of practical work in MT. Chapter 5 provides project details.

CHAPTER 5: RESEARCH DESIGN AND METHODOLOGY

5.1 Introduction

The purpose of this chapter is to elaborate on the research design, methodology and interventions as briefly introduced in Chapter one. Chapter five also highlights and explains in detail the population, sampling and interventions with regard to reliability, trustworthiness and ethical procedures, as well as how these were integrated and implemented in the VTEE 222 and VTEE 312 modules (courses). Background information with regard to Mechanical Technology, the automotive discipline, and the modules are also provided. The research paradigm and design are outlined below.

5.2 Research paradigm, design and methodology

5.2.1 Research paradigm

According to Hall (2012) and Morgan (2014), a paradigm is a perspective, or a shared worldview to direct an investigation with the aim to answer the research questions. Educational research can be linked to ontology, epistemology and methodology (Mustafa, 2011).

* **Ontology** deals with the nature and structure of 'reality' to make sense of and understand the world (Al-Saadi, 2014; Guarino *et al.*, 2009). In this study the nature of certainty or realism is pragmatism as related to the understanding of the students' PBL activities in MT. Ontology is thus "assumptions about the nature of reality" (Kaushik & Walsh, 2019:1).

* **Epistemology** can be defined as the theory of knowledge (understanding) of reality (Audi, 2010). According to Maree (2010:55) "epistemology relates to how things can be known", how truths or facts can be exposed and revealed. It thus looks at how individuals see and know reality, the method of knowing, or the nature of reality. Epistemology is thus assumptions about how we know the world, how we gain knowledge and the relationship between the knower and knowledge (Roos *et al.,* 2016; Kaushik & Walsh, 2019). This study mainly involved the development of knowledge in practical contexts and focused on the major underpinning of pragmatic epistemology, that knowledge is based

on experience as mentioned by Kaushik and Walsh (2019).

* **Methodology** is influenced by the ontological and epistemological theories and it refers to the following question: How can students accomplish gaining the desired knowledge and understanding? (Koshy, 2010; McNiff, 2014). In this study, the methodology indicated how students gained knowledge in MT to enhance their SDL. The three elements (ontology, epistemology, and methodology) are interdependent on each other (see Fig 5.1) and the influence thereof should, therefore, show a researcher's personal values, experiences and interaction with the participants (Johnson, 2012).

In this study, the point of departure is pragmatism. A pragmatic view can, according to Pratt (2016:510), be “applied epistemology, methodology as well as an ontology”. According to Hothersall (2016:360), “Pragmatism has the potential to act as an organising theoretical framework, taking account of the role of both ontology and epistemology, acting as a functional and integrative methodology for further enhancement of practice-based knowledge and research activity” (see Figure 5.1).

* **Pragmatism** can be backtracked to the philosophies of Donald Davidson, John Dewey, and Richard Rorty (Rorty & Williams, 2009). *Pragmatism* originated from the Greek word “pragma”, which means action (Kaushik & Walsh, 2019). This implies that action is the primary concept of pragmatism and that pragmatists believe that reality (truth) is what works best for understanding and explaining a specific research question or problem (Teddlie & Tashakkori, 2009; Kaushik & Walsh, 2019). Pragmatist worldview also argues that both qualitative and quantitative methods could be used in combination within a single study (Creswell & Creswell, 2017). According to Creswell (2017:62), “a pragmatist worldview is practice-orientated, pluralistic, problem-centred and focused on consequences of action”.

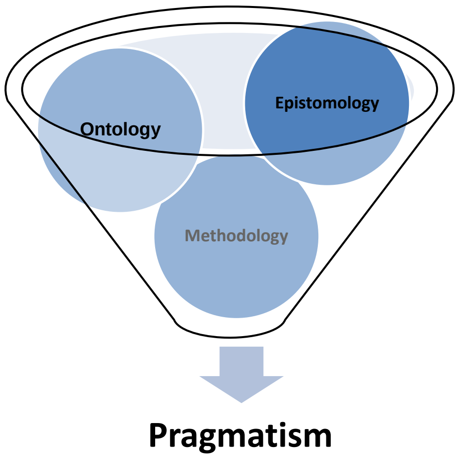


Figure 5:1: Interdependence of philosophical theories
Source: Compiled by researcher

5.2.2 Research design and methodology

A research design provides a comprehensive structure for the processes that a researcher follows in order to answer the research question (Leedy & Ormrod, 2013). The research design thus provides a research plan or blueprint. There are, according to Creswell and Creswell (2017), three approaches with regard to research design that can be used, namely qualitative, quantitative and mixed-method. The latter was selected by the researcher as the mixed-method approach allows for better results than qualitative or quantitative research on their own, as it involves both methods applied in tandem (Creswell & Creswell, 2017). Creswell and Creswell (2017:17) call a mixed-methods approach “pragmatic worldview, collection of both quantitative and qualitative data in one study”.

A mixed-methods approach proposes a set of procedures or rules to adhere to with regard to collecting, analysing and mixing of data (Maree, 2010). Creswell and Creswell (2017) distinguish among four mixed-method research designs, namely explanatory, exploratory, triangulation and embedded methods. However, a general mixed method approach was used in this study as this allowed the researcher to best understand the research questions (Harrison, 2013; Hesse-Biber, 2010). In this study the emphasis was on qualitative research, therefore, a QUALquan mixed-method approach was followed.

5.2.3 Population and sample

The population consisted of 12 students (N = 12) in 2017 (VTEE 222 course) and 10 (N = 10) in 2018 (VTEE 312 course). All students completed the Williamsons questionnaire and participated in focus group discussions. However, for the individual interviews, seven individual students were involved (see Section 5.9.3).

5.3 Williamson Self-Rating Scale of Self-Directed Learning (SRSSDL)

The quantitative research instrument used for this study was the Williamson questionnaire, also called the Williamson Self-Rating Scale of Self-Directed Learning (SRSSDL). This instrument, (see addendum D) aimed at examining the relationships among constructs. The SRSSDL comprises five broad constructs, namely: Awareness, Learning strategies, Learning activities, Evaluation and Interpersonal skills.

Awareness refers to the metacognitive skill of reflecting on one's own cognitive process and one's awareness of doing while *learning strategies* include the ability to develop skills and to link theory with practice aimed at developing SDL skills, problem-solving skills, and enhanced communication (Prasanna, 2017; Williamson, 2007). *Learning activities* involve a series of inter-related learning actions, allowing learners to take responsibility for their own learning (Darling-Hammond *et al.,* 2019). The *evaluation* construct demonstrates the usefulness of the assessment in the teaching and learning process and the *interpersonal* construct relates to the interaction between the teachers, students and peers, communication, time management and their ability to complete learning tasks (Darling-Hammond & Cook-Harvey, 2018; Williamson & Seewoodhary, 2017).

Students need to apply various *learning strategies* in order to become self-directed and learning strategies such as problem-based learning and cooperative teamwork provided opportunities for students to enhance their self-directed learning (Bagheri, 2013). *Learning activities* include the students' ability to set their own goals, learning outcomes, learning pace and to select appropriate assessment methods (Williamson, 2007).

The scoring sheet for the SRSSDL are outlined in Table 5.1. When adding the total scores of each construct, the level of self-directedness can be established. Although the SRSSDL constructs can be used to identify areas wherein individuals need to pay attention, the total scores are an indication of their self-directedness (see Table 5.1, Figure 6.7 and 6.8).

Table 5:1: Calculating total Likert-scores of SRSSDL

Scores	**Variables**	**1**	**2**	**3**	**4**	**5**	
Questions 8 – 19	Awareness (AW)						Total score =
Questions 20 – 31	Learning strategies (LS)						Total score =
Questions 32 – 43	Learning activities (LA)						Total score =
Questions 44 – 55	Evaluation (E)						Total score =
Questions 56 – 67	Interpersonal skills (IS)						Total score =

Add all the scores of each construct for each participant (the totals of the numbers marked on the Likert-scale). For example, if a participant marked 1 at each question in the questionnaire, the total will be 60, as there are 60 questions in the Williamson questionnaire.

Total AW 8–19	+	Total LS 20–31	+	Total LA 32–43	+	Total E 44–55	+	Total IS 56–67	=	Total Between 60 and 300

The lowest score a participant can thus achieve is 60 and the highest is 300 (see Table 5.2). This was used to interpret the quantitative data (see Figures 6.7 and 6.8).

Table 5:2: Interpretation of total Likert-scores (Williamson, 2007)

Scoring range	Level of self-directedness	Interpretation
60 – 140	Low	*Guidance is definitely needed from the educator. Any specific changes necessary for improvement must be identified and possible complete re-structuring of the methods of learning.*
141 - 220	Moderate	*This is halfway to becoming a self-directed student. Areas for improvement must be identified, evaluated and a strategy adopted with educator guidance when necessary.*
221 - 300	High	*This indicates effective self-directed learning. The goal now is to maintain progress by identifying strengths and methods for consolidation of the student's effective self-directed learning.*

Quantitative research is often used for testing theories by investigating the connection between variables and the final objective, in an effort to order, define, describe, foresee and understand a phenomenon (De Vos *et al.*, 2011). Scholars see quantitative research (using numbers) as systematic, meticulous, rational and objective to generalise findings and results to the phenomena being studied and points out three important elements, namely: objectivity, numerical values and generalisation (Maree, 2016).

5.4 Data collection

The SRSSDL developed in this study, using the Delphi technique, was found to be a valid and reliable instrument in identifying student's level of self-direction in learning. "Students, while responding to the items of the SRSSDL, will develop a clearer concept and understanding of self-directed learning behaviour, identify the areas of their own strength and weaknesses and select appropriate strategies for improvement of their self-directed learning skills" (Williamson, 2007:76).

5.4.1 Quantitative data collection

The Williamson's questionnaire was used before each intervention (pre-test) and after each intervention (post-test) with the qualitative process in between. Thus, students completed the pre-test questionnaire before the start of the first intervention in August 2017, followed by a 12-week intervention, during which the qualitative data was collected and at the end of the intervention in September/October 2017, the post-test questionnaire followed. In 2018, the same procedure was followed starting in February 2018 and ending in May 2018 (see Tables 5.7 and 5.9). The dates for the intervention work were adjusted to correlate with the dates of the University and the Work Integrated Learning (WIL) period.

Participants completed the Williamson questionnaire four times over a period of two semesters to establish their self-directed readiness before and after two cycles (interventions).

5.4.2 Qualitative data collection

Qualitative research designs usually incorporate different methods and approaches to conduct an investigation. These approaches can differ widely from each other, however they usually share the following: they focus on a phenomenon that occurs in a natural setting and they involve the phenomenon to be studied in its full intricacy (Leedy & Ormrod, 2013).

In this study, design-based research (DBR) was conducted in two cycles and the qualitative data collection comprised focus group interviews, project sheets, observations, and individual semi-structured interviews (see addendum B and C and Section 6.7).

5.5 Data analysis

In this study, both quantitative and qualitative data were analysed to answer the research questions.

5.5.1 Quantitative data analysis

Quantitative results were analysed by the Statistical Consultation Services of the NWU and interpreted by the researcher. Statistical analysis involved mainly descriptive statistics. In this study, the Williamson Self-Rating Scale of Self-Directed Learning (SRSSDL) was used as it measures five key constructs of SDL, namely *awareness*, *learning strategies*, *learning activities*, *self-evaluation* and *interpersonal skills* (Williamson, 2007).

5.5.2 Qualitative data analyses

Qualitative data were transcribed, analysed and categorised by the researcher using the Atlas.ti^{TM} program. Data were organised into different documents and folders before Atlas.ti^{TM} could be used. The analysis strategy included data-driven as well as concept-driven coding as described by Gibbs (2018). The codes were used to allocate and link different activities, phrases, remarks, perceptions and experiences of participants during the intervention (see Figure 6.9). Different themes were identified from the emerging data (see chapter 6).

At the end of the coding process, the researcher identified 298 codes, which were organised into 30 categories (see Table 6.10), which could be related to five themes.

5.6 Reliability and trustworthiness

5.6.1 Reliability of quantitative research

The number of participants were low (N=12). As a result, only descriptive statistics were used.

5.6.2 Trustworthiness of qualitative research

Trustworthiness is important when conducting qualitative research. Scholars suggest methods such as credibility, dependability, confirmability and transferability in developing trustworthiness (Cope, 2014; Lincoln & Guba, 1986).

In this study, the data was recorded as MP3 files and transcribed by an assistant. The transcriptions were then rechecked by the researcher and spot-checked by a third party who confirmed credibility of the transcripts. Credibility and dependability were ensured by the presence of a non-participating research assistant when interviews and minutes were recorded, by employing a third party to assist with the coding and by using a colleague to verify the accuracy of the transcriptions of the interviews and minutes.

Confirmability (the degree of neutrality) in this study was ensured by feedback from respondents and not researcher bias.

5.7 Ethical aspects of study

Approval was obtained from the Faculty of Education Ethics Committee (EduREC) (NWU-00484-17-A2) and the study was conducted in accordance with the stipulations within the ethical codes of the Faculty of the North-West University (NWU) (see Addendum A and Q). A list of factors adhered to follows below.

5.7.1 Informed consent

The promotor (independent person) informed all participants beforehand, with regard to the scope of the research, and the students had a choice regarding participation. All students readily agreed to take part, they were also aware of the fact that participation or non-participation will have no direct influence on their module marks and they knew that participation was voluntary and that they could withdraw their participation at any stage. Students/participants completed informed consent (see Addendum K and L) before they were allowed to take part in the research project and they agreed that their data could be used for research purposes.

5.7.2 Student privacy and confidentiality

The NWU is committed to the Promotion of Access to Information Act 2 of 2000 and the Protection of Personal Information Act (POPI Act 4 of 2013) and therefore confidentiality of all participants were respected at all times. Although students had to include their student numbers when completing the questionnaires, the numbers were only used for statistical procedures (pre-test and post-test). Students used number tags to identify the artefacts that they developed in teams and also to ensure their confidentiality, for example, A1 and B6.

5.7.3 The role of the researcher

During the interventions and the project developments I, the researcher, had a 30% obligation (hPBL allows for mini-lectures and demonstrations). The researcher was facilitator, lecturer and researcher at the same time. These were:

- Facilitate. Help the students to understand their objectives during the interventions, assist participants to plan their activities, enable the groups to collaborate in teams;
- Workshop manager, regarding general safety, tools equipment, etc.;

- Instructor, by teaching students hands-on skills when needed. For example, soldering, welding, crimping, bending, using basic tools and how to apply safety measures;
- Mentor, in developing informal and formal relationships between myself and students and also between students themselves, in providing structure to the processes, in the formal and informal transmission of know-how and by sharing the experience with regard to workshop procedure;
- Assistant, when administering the interviews and questionnaires; and
- Preparation and compilation of interviews.

5.8 Design-based research

Design-based research (DBR) evolved during the 21st century as a practical research approach bringing research practice to classrooms by bridging the gap between teaching and research (Anderson & Shattuck, 2012). DBR interventions are compatible with a "wide variety of multiple methodologies" such as mixed-methods (Anderson & Shattuck, 2012:17). Moreover, DBR can also be associated with pragmatism (Bell *et al.,* 2013; Fraefel, 2014; McKenney & Reeves, 2018).

Design-based research was part of this study with the use of two cycles (interventions). The cycles, with the aim to investigate real world, practical instructive problems (making artefacts), were used in an effort to gain understanding thereof and to achieve multiple outcomes. The design cycles consisted of the design of electrical systems, including circuit testing, correct wiring methods, compiling wiring diagrams and mechanical systems, including steering gear, construction, materials, joining and selection of processes. The main idea behind the design-based research was to reach more than one outcome, to find solutions for instructive problems and to find understanding and knowledge (Tee & Lee, 2011) (see Figure 1.3).

Each intervention served as a cycle of design. In Figures 5.2 and 5.3 the detail of the design-based cycles are outlined as interpreted by Fraefel (2014) and the implementation thereof in this study.

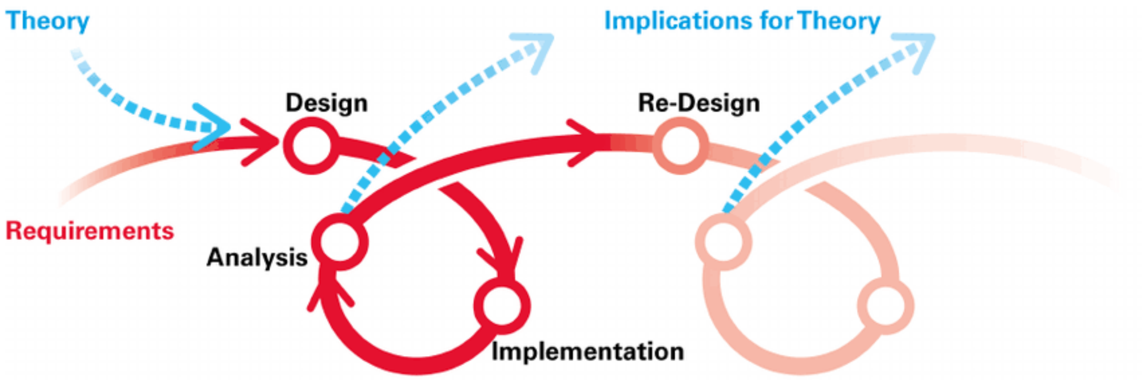


Figure 5:2: Design-based research

Source: Fraefel (2014)

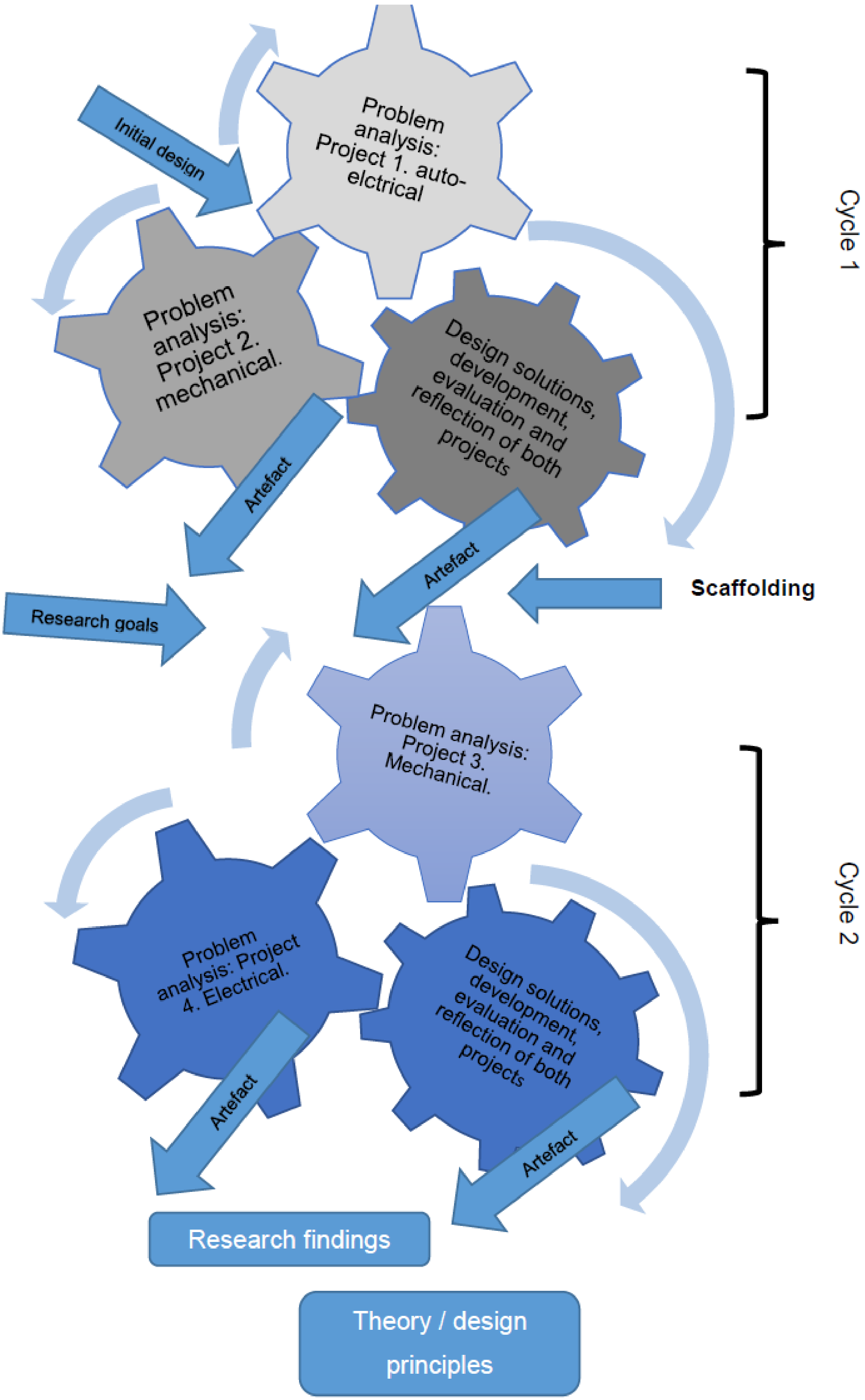


Figure 5:3: The design-based research cycles used in this intervention

Source: Compiled by researcher

In this research, DBR was used as two cycles of design involving four projects (see Figure 5.3). When using design-based research the following can be used as a guide:

- Design-based research methods should include cycles of design and re-design in order to assess inquiry, to enhance the design and to acquire deeper comprehension of the problem that is being solved (Euler, 2014);
- Constant collaboration between participants and researchers should be allowed during the entire intervention (Coghlan & Brannick, 2014); and
- During design-based research the aim is that participants should learn something while designing and not only learn how to design something, address real-world problems and achieve particular outcomes (Bernhard *et al.*, 2016; Edström & Kolmos, 2014).

To enhance SDL it is crucial for each team member to play a role when making decisions and to share knowledge in order to reapply the newly acquired knowledge back to the problem (Havenga, 2016). While developing a project, students need to learn skills such as goal setting, problem analyses, self-study, design, development, (search for information), self-management and self-reflection (Havenga & Van Wyk, 2017)(see Figure 1.3).

5.9 Interventions – General Orientation

Interventions were implemented in VTEE 222 and 312 practical sessions during 2017 and 2018. Before 2017, these practical sessions were presented in a traditional face-to-face manner. However, when planning the 2017 intervention, the facilitator had to rethink the entire structure of the practical sessions of these modules, especially in terms of the integration of hybrid problem-based learning. One of the challenges of planning the interventions was selecting appropriate projects suitable for the knowledge and skills level of second- and third-year students. The facilitator (researcher) also had to make allowance for appropriate scaffolding or progression with regard to the skills required to move from the second to the third year, by making projects more challenging and by providing less assistance by means of mini-lectures and demonstrations. The researcher decided on two mechanical projects, which required skills such as joining and bending of different materials, and two auto-electrical projects, requiring skills such as soldering and connecting electrical auto wiring.

In Figure 5.4 and 5.5 the cycles are explained, for example, in 2017, projects 1 and 2 were developed simultaneously (parallel development) for ± 6 weeks by the two groups and after ± 6 weeks the groups swapped workstations to work on the other project. A parallel development process was used in 2017 and a series development process during 2018, as this was the best way to accommodate the students regarding the available time, space and equipment. In other words in 2017, while group A was doing project 1, group B was doing project 2, and after ± 6 weeks, group A did project 2 and group B did project 1. In 2018, both groups A and B did project 3 for ± 6 weeks and then both groups did project 4 for ± 6 weeks.

By careful planning, projects 3 and 4 were placed on a higher academic, technical and skills level and students had to use more advanced methods, processes, and skills to complete these projects. The lecturer provided less mini-lectures and demonstrations during project 3 and 4. The abovementioned adjustments with regard to the higher academic level of the projects were achieved by designing projects 3 and 4 in such a way that some of the knowledge, understanding, and skills obtained during the first intervention (project 1 and 2) had to be used to plan, design and complete projects 3 and 4. For example, project 4 focused on more advanced auto electrical wiring by subjecting students to a real-life problem. They had to complete the starting and charging wiring system of a real engine in order to make the engine start with a key, run uninterrupted and use the alternator on the engine to charge the battery. The lecturer provided less support during project 3 and 4 (see Addendum J for full detail of projects).

In 2018, the problems became more complex. The auto electrical project, for example, included more advanced and complicated auto wiring diagrams (see Table 5.8) and required the use of detailed testing procedures. For example, a much thicker wire was needed to feed the starter, and the choke and carburettor circuits needed to function correctly. In addition, the lecturer provided less than 20% assistance to participants. The mechanical project required more in-depth research with regard to the "Sterling heat engine's" complicated joining methods and the use of different materials in order to complete the project (see Addendums H and I).

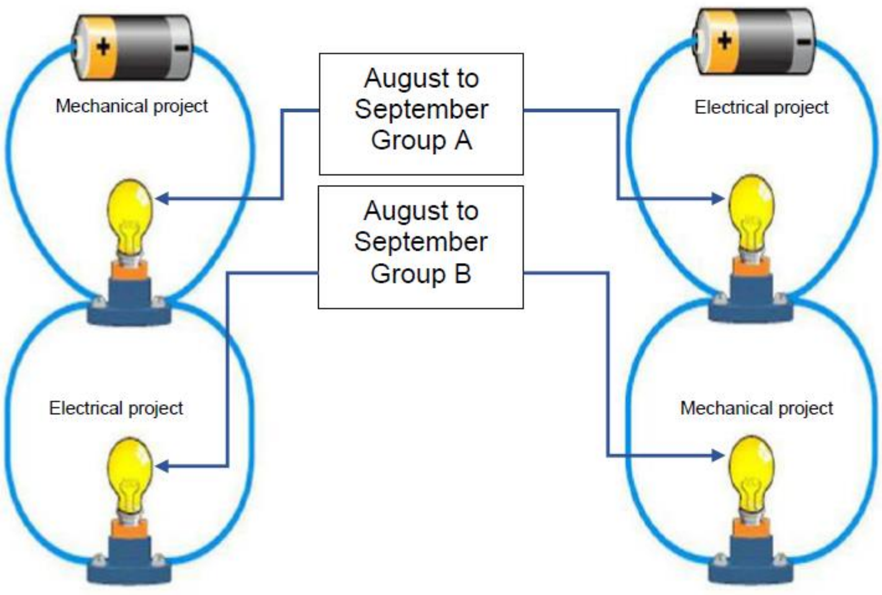


Figure 5:4: 2017 Projects developed in parallel

During the first project in **2017,** two weekly group sessions (interviews) were held and at the end of ± six weeks, students from each team (n = 4) were randomly selected for the semi-structured interviews (see Table 5.4). Teams also kept project sheets that were updated weekly (see Addendum O). The teams then changed working stations and each group started with the other project that was again finished in more or less six weeks after which the same procedures regarding interviews were followed.

During the hPBL project in **2018,** two weekly group sessions (interviews) were held and at the end of ± six weeks, students from each team (n = 3) were randomly selected for the semi-structured interviews (see Table 5.5). Teams also kept project sheets that were updated weekly (see Addendum O). Both teams completed project 3 for ± six weeks and thereafter both teams started with project 4 for ± six weeks.

Figure 5.4 shows the parallel development of the projects in 2017 and Figure 5.5 shows the series development of the projects in 2018.

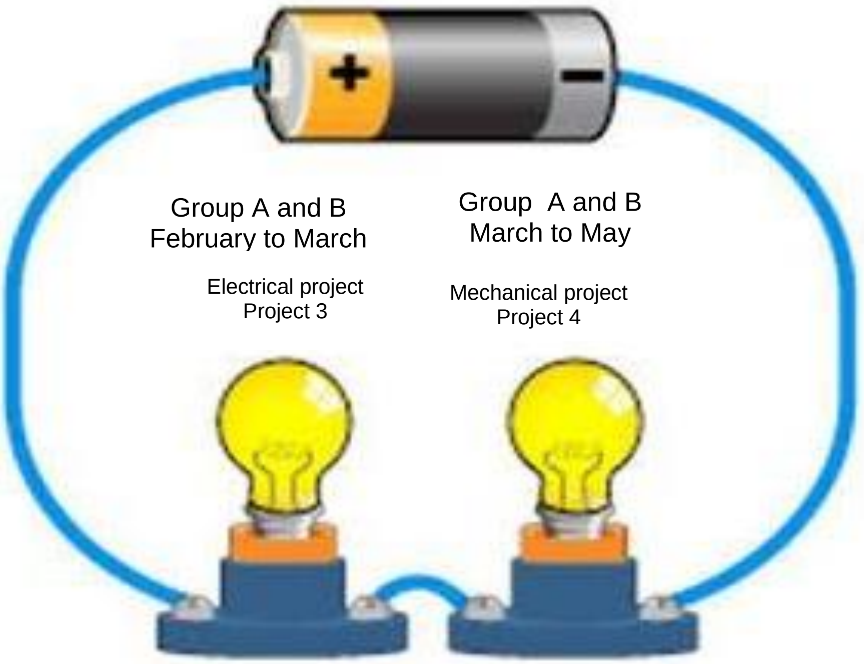


Figure 5:5: 2018 Projects developed in series

5.9.1 Implementation of hPBL in both cycles

The hPBL model was introduced in seven steps (see Chapter 7) during the first and second intervention. The design of the hPBL model used in this study is shown in Table 5.3.

The lecturer involvement was kept low by allocating more or less 30% of the time by means of mini-lectures, demonstrations and other forms of assistance in 2017 and less than 20% during 2018.

In Table 5.3 the framework for the application of hPBL for all four projects are provided. Although an adapted 7-jump model was used, the researcher spent some time regarding the identification of foreseen and unforeseen health and safety risks, as this is the area where the 7-jump model falls short in a technical environment (see Chapter 7).

Table 5:3: Framework for problem-based projects in MTA

Steps of problem-based projects	Application in MTA
1. Conceptualise Clarify the consepts	1. Conceptualise Present students with the problem. Students clarify and elaborate on concepts.
2. Define the problem context Discuss the problem context and refer to general problem understanding (see Table 2.2)	2. Discuss the problem content Define the electrical, mechanical and safety content regarding the problem at hand.
3. Identify knowledge and needs (brainstorm) Identify current knowledge and learning needs to solve the problem	3. Identify knowledge and needs Identify prior knowledge and new knowledge to be dealt with such as how to fit the wheels in project 1.
4. Categorise ideas Repeat previous steps. Generate new ideas	4. Categorise and structure ideas Explain problem in different ways. Ask questions and structure ideas.
5. Formulate learning objectives and goals Scrutinise for appropriate objectives regarding the problem. Decide exactly what should be done and how	5. Identify and formulate The need to solve the problem at hand. Find consensus regarding what should be done and how. Check if equipment supplied is appropriate. Apply safety measures. Processes needed.
6. Investigate design and develop Focus on the innovative design and development of a solution to the problem	6. Design and develop (find resources) Find appropriate resources. Team design, plan and build unique artefact.
7. Evaluate and reflect Ensure that the objectives and assessments are aligned and assess each member's responsible involvement in all hPBL activities	7. Reflect and assess Students report on progress, challenges, suggest future improvements, and elaborate on team member's involvement and individual responsibilities.

Source: Compiled by researcher

The four interventions were closely linked with the practical work outlined in the study guides for Mechanical Technology Automotive (MTA) for 2nd and 3rd year studies (Benade, 2016; Benade, 2017).

The detail of each individual project is provided in Tables 5.7 and 5.9 and photographic evidence of both interventions are provided in chapter six. (see Tables 6.3 - 6.6).

5.9.2 Participants

Although 12 participants started the intervention in 2017, only 10 of those students participated in the second intervention. This explains the different number of participants in some of the tables and graphs. The results of these 10 participants allowed the researcher to analyse the progress of all 10 participants over two interventions as part of the design-based research.

In 2017, participants (N = 12) were divided into two equal groups, group A and group B and each group was divided into teams of two members per team (see Table 5.4). Members of the teams received ‘name cards’ labelled with an A or a B followed by a number ranging from 1 to 12, for example, A1 and B6. There were thus six members (3 teams) in one group and six members (3 teams) in the other group for the duration of the first intervention.

In 2018 (N = 10) the same groups were involved, however the team members and sizes changed to comply (see Table 5.5) with the availability of components (there were only four complete engines available) and space. This resulted in four groups, two with 3 members each and two with 2 members each (see Table 5.5).

Teams were randomly selected and allocated to groups in 2017, with the use of a simple program, to ensure all members had an equal chance of being part of a specific group or team. In 2018, participants retained their original ‘name tags’, but the individuals had the freedom to select teammates. The freedom to choose their own teammates was done to determine if this could have positive results in further improvement of teamwork.

Data. Qualitative data from 2017 (see Table 5.4) consisted of 12 focus group meetings, 4 individual interviews, 6 project sheets and one observation and the qualitative data from 2018 consisted (see Table 5.5) of 8 group meetings, 3 individual interviews, 4 project sheets and one observation (see Table 6.7).

Table 5:4: Individual contributions to qualitative data 2017

Team	Participant	Individual interview	Group interview 1	Group interview 2	Project sheet	Researcher's notes (observations)
Team 1	A1	Yes	Yes	Yes	Yes	Yes
	A5	No				
Team 2	A3	No	Yes	Yes	Yes	
	A7	No				
Team 3	A9	Yes	Yes	Yes	Yes	
	A11	No				
Team 4	B2	Yes	Yes	Yes	Yes	
	B4	No				
Team 5	B6	Yes	Yes	Yes	Yes	
	B8	No				
Team 6	B10	No	Yes	Yes	Yes	
	B12	No				

Table 5:5: Individual contributions to qualitative data 2018

Team	Participant	Individual interview	Group interview 1	Group interview 2	Project sheet	Researchers notes (observations)
Team 1	A11	Yes	Yes	Yes	Yes	Yes
	B2	No				
	B4	No				
Team 2	A1	No	Yes	Yes	Yes	
	B6	Yes				
	B8	No				
Team 3	A3	No	Yes	Yes	Yes	
	A5	No				
Team 4	B10	Yes	Yes	Yes	Yes	
	B12					

5.10 2017 Intervention - Cycle 1

The intervention in 2017 entailed two projects, namely a mechanical project (wire cart) and an auto-electrical project (light board). The main purpose of this intervention was to implement hPBL in practical sessions and to develop students' SDL. Students applied 7 hPBL steps to design, develop and complete the projects.

The detail, planning and application of the hPBL is shown in Table 5.7 and the detail of the individual projects are provided thereafter.

To ensure academic scaffolding the researcher adjusted specific parameters of the projects with regard to the level (see Figure 2.2), the expertise and the detail of the project as well as the involvement of the students and the lecturer. For example, the size of the groups were changed to comply with the availability of equipment. The lecturer aimed at providing just enough support (mini-lectures and demonstrations) at just the right time in order to allow students to participate in activities and to gain skills which they would have been unable to complete unaided. The extent of the projects were changed in order to foster progression in practical knowledge, skills and competencies.

Before the students commenced with any of the projects, they had to submit their planning and research regarding the project. In order to assist students with their planning, the researcher provided time planning sheets (see Table 5.6) and electrical diagrams (for the first electrical project) (see Figure 5.5). Students had to make detailed drawings of their projects before they could start with the development thereof.

Note that students were informed with regard to the use of equipment, safety regulation and basic workshop conduct before the start of the intervention.

Table 5:6: Time management sheets for 2017 (similar planning for both interventions)

Konsep beplanning: 2017 / *Draft planning: 2017 VTEE 222*												
Aktiwiteit / *Activity*	**7**	**14**	**21**	**28**	**7**	**14**	**28**	**9**	**16**	**23**	28	
	Aug				Sept			Oct				
Voorligting, voltooing van ingeligte toestemming en verdeel in groepe / *Information, complete consent and group allocation*	X											
Studente begin met beplanning (1) en voltooi projekstate / *Students start with planning (1) and complete project sheets*	X											Project 1 and 2
Studente handig voorbereiding van projekte en tydraamwerk in en begin werk / *Students hand in planning of projects and time schedules and start working*		X										
Studente werk aan projekte (1), voltooi projekstate en hou fokusgroep vergadering / *Students work on projects, complete project sheets and have focus group meeting*			X									
Studente werk aan projekte / *Students work on the projects*				X								
Studente werk aan projekte, voltooi projekstate en hou fokusgroep vergaderings / *Students work on projects, complete project sheets and have focus group meetings*					x							
Studente voltooi projekte 1 en 2 en voltooi projekstate / *Students complete projects 1 and 2 and complete project sheets*						x						
Studente begin met beplanning (2) en voltooi projekstate / *Students start with planning (2) and complete project sheets*						X						Projek 2 and 1
Studente handig voorbereiding van projekte en tydraamwerk in en begin werk / *Students hand in planning of projects and time schedules and start working*							X					
Studente werk aan projekte (2), voltooi journale en hou fokusgroep vergadering / *Students work on projects, complete journals and have focus group meetings*								X				
Studente werk aan projekte 1 en 2 / *Students work on projects 1 and 2*									x			
Studente werk aan projekte, voltooi projekstate en hou fokusgroep vergaderings / *Students work on projects, complete project sheets and have focus group meeting*										X		
Studente voltooi projekte 1 en 2 en voltooi projekstate / *Students work on projects 1 and 2 and complete project sheets*											X	

Table 5:7: Cycle 1 – intervention 2017

2017 Intervention (1)

Semester 2 - 2017, weeks 1–6

Group	Participants	Team	Project	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Group A	A1, A5	Team 1	Project 1-Wire cart	Williamson's pre-test, topic introduction, research and problem exploration and planning	Design sketches, project development and focus group meeting	Project development, costing, testing and groupwork	Project development testing, groupwork and focus group meetings	Project development, testing and groupwork	Finalise project development, testing, groupwork and final focus group meeting
Group A	A3, A7	Team 2	Project 1-Wire cart						
Group A	A9, A11	Team 3	Project 1-Wire cart						
Group B	B2, B4	Team 4	Project 2 -Light board	Williamson's pre-test, topic introduction, research and problem exploration and planning	Design sketches, project development and focus group meeting	Project development, costing, testing and groupwork	Project development testing, groupwork and focus group meetings	Project development, testing and groupwork	Finalise project development, testing, groupwork and final focus group meeting
Group B	B6, B8	Team 5	Project 2 -Light board						
Group B	B10, B12	Team 6	Project 2 -Light board						

Semester 2 - 2017, weeks 7–12

Group	Participants	Team	Project	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12
Group A	A1, A 5	Team 1	Project 2 Light board	Topic introduction, research and problem exploration and planning (free hand)	Design sketches, project development and focus group meeting	Project development, costing, testing and groupwork	Project development testing, groupwork and focus group meetings	Project development, testing and groupwork	Williamson's post-test, Finalise project development, testing, groupwork and final focus group meeting
Group A	A3, A7	Team 2	Project 2 Light board						
Group A	A9, A 11	Team 3	Project 2 Light board						
Group B	B2, B4	Team 4	Project 1-Wire cart	Topic introduction, research and problem exploration and planning (free hand)	Design sketches, project development and focus group meeting	Project development, costing, testing and groupwork	Project development testing, groupwork and focus group meetings	Project development, testing and groupwork	Williamson's post-test, Finalise project development, testing, groupwork and final focus group meeting
Group B	B6, B8	Team 5	Project 1-Wire cart						
Group B	B10, B12	Team 6	Project 1-Wire cart						

5.10.1 Project 1: Auto Electrical System lights and control

*** Context:** Project 1 was an auto-electrical project and ± six weeks were allocated for the development. Note that, many students did not have any previous knowledge regarding electrical circuits.

*** Scenario:** In this project, you need to build a unique model of a vehicle's primary wiring system, using your own design. Although all teams will receive a metal board with a number of globes fitted, you have to design the wiring layout, the position of the switchgear and the testing and connection of the different switches, fuses and components yourself. A wiring sheet will be provided, the lecturer will demonstrate how to solder electrical wires to connectors, how to use the multi-tester, how to test switchgear and provide information regarding safety rules. You need to decide on the layout, length, size, colour coding and route of the conductors. (You will only be provided with a metal board representing the car body, equipment kit and design sheet). The project should include all wiring to fit inside the board and for all the lights to illuminate to present the different units such as flickers, park lights and other components. The project should include soldering, use of electrical connectors, use of a multi-meter, male and female connectors and various switches, dimmers, spotlights (to operate with switch and relay only, activated by main beam signal), ignition key, fuses, and a 12v battery. You decide how to address the abovementioned project, however, the lecturer will provide a mini-lecture regarding the use of tools, the welding and soldering process as well as the safety measures you need to adhere to. You should search for appropriate examples of primary wiring systems.

* PBL steps to follow:

Conceptualise (to understand what you need to do)

The team should ensure that all members understand the problem by clarifying all relevant terms and sub-problems.

Define the problem (to fully understand the problem at hand)

Ensure you clearly understand and agree on the problem and fully define it (for example, what component should be connected where). Discuss the problem context with your peers and come to an agreement, bearing all aspects in mind.

Identify knowledge and needs (brainstorm)

Identify current knowledge and needs as required to solve the problem (for example, who has prior knowledge regarding auto electrical systems). Each member of the group should express his or her opinion and ideas regarding the problem.

Categorise and structure ideas

You may revisit previous steps as required. Identify tentative solutions to the problem. Discuss the possibilities from all angles (for example, there is more than one way to test and connect the circuits). The lecturer will assist by probing various questions. Suggest tentative steps applicable to solving the problem.

Formulate and identify learning objectives

Reach consensus regarding all facets of the problem. Decide what you need to do (outcomes) and clearly formulate your learning objectives. Compile an exhaustive list and discuss possible dilemmas that may arise while solving the problem and plan the next step, for example, what do you need to know regarding electrical circuits?

Investigate, design and develop

Find appropriate sources, such as primary auto wiring and information regarding the use of switchgears, relays and flicker units within your groups. Focus on the innovative design and development of a solution to the problem. Finally, connect all electrical cables and conduct final testing.

Evaluate and reflect

Ensure that the objectives are aligned and assess each member's responsible involvement in all the hPBL activities. Complete your project reports and submit a portfolio comprising all designs and relevant documents.

5.10.2 Project 2: Wire car (‘draadkar’)

*** Context:** Project 2 was a mechanical project and ± six weeks were allowed for the development. Note that most students have some prior knowledge (some very limited) regarding design and working with wire and steel.

*** Scenario:** In this project, you need to build a unique wire model of a vehicle of your own design. Although all teams receive various materials such as wire, aluminium sheeting wheels and tools, you have to design a model of a car (wire cart), the layout, the shape, size, suspension, scale to use and steering layout. The lecturer will provide less help than in project 1, as he will only demonstrate how to join galvanised wire and provide some mini-lectures regarding safety rules. You decide on the layout, length, size, colour, suspension, steering layout and other detail. You decide on all aspects of this project. You should search for appropriate examples and information of cars and steering layouts. The project needs to meet the following specifications: Apply theoretical knowledge and practical skills with regard to basic joining methods, steering layouts, properties of materials, automotive design and basic shaping, represent a scaled down recognisable model of some vehicle and the steering needs to operate via a long steering rod. You now have the opportunity to show how creative and innovative you are as you have a free hand in the design of this project. Use your imagination and feel free to do as much research of this topic as you like.

*** PBL steps to follow**

Conceptualise (to understand what you need to do)

The team should ensure that all members understand the problem by clarifying all relevant terms and problems.

Define the problem (to fully understand the problem at hand)

Make sure you clearly understand and agree on the problem in order to fully define the problem. (What shape are we aiming to copy, what size should panels be, etc.). Discuss the problem content with your peers and agree to a general problem understanding.

Identify knowledge and needs (brainstorm)

Identify current knowledge and needs as required to solve the problem (for example, do I have any prior knowledge regarding welding, soldering, shaping, etc.). Each member of the group should express his or her opinion and ideas regarding the problem.

Categorise and structure ideas

You may revisit previous steps as required. Identify tentative solutions to the problem. Discuss the possibilities from all angles (for example, there is more than one way to join materials or to fit the suspension and steering). The lecturer will assist by probing various questions. Suggest tentative steps applicable to solving this problem.

Formulate and identify learning objectives

Reach consensus regarding all facets of the problem. Decide what you need to do (outcomes) and clearly formulate your learning objectives. Compile an exhaustive list and discuss possible dilemmas that may arise while solving the problem and plan the next step (for example, what do I need to know regarding joining, shaping materials, suspension and steering systems?).

Investigate, design and develop

Find appropriate sources, such as examples of basic shapes, joining, suspension and steering layouts in your groups. Focus on the innovative design and development of a solution to the problem. Finally finish the project and test-drive it.

Evaluate and reflect

Ensure that the objectives are aligned and assess each member’s responsible involvement in all the hPBL activities. Does the *wire car* look like it should, was the joints sturdy, is the car symmetrical and does the steering operate correctly?

After cycle one (Intervention 1) a few adjustments were made regarding the teams and the detail for projects 3 and 4 for cycle 2 (Intervention 2). The detail of the differences between cycle 1 and cycle 2 are outlined in Table 5.8.

Table 5:8: Project development from 2017 to 2018

Aspects	Cycle 1 – 2017 (Intervention 1)	Cycle 2 – 2018 (Intervention 2)
Project execution	Parallel	Series
Participants	12	10
Modules	VTEE 222	VTEE 312
Problem analyses	**Project 1: Auto-electrical system lights and control** **Project 2: Wire car**	**Project 3: Auto-electrical starter and alternator** **Project 4: Sterling engine**
Progression	One mechanical and one electrical project in cycle 1. These projects (project 1 and 2 in 2017) progressed to the next project (project 3 and 4 in 2018). **Mechanical:** Progressing from the design and development of a basic wire cart to the design and development of a replica of a tin can Sterling engine. This required higher levels of thinking, research and design as making such a replica has endless possibilities.	Progression from cycle 1 to cycle 2. One mechanical and one electrical project in cycle 2. These projects (project 1 and 2 in 2017) progressed to the next project (project 3 and 4 in 2018). **Electrical:** Progressing from the design and development of a light circuit replica to a real-world engine that needs to run and charge a battery. All other related components, such as pilot lights, electric choke, electric idling valve and switches to operate correctly. This required higher levels of thinking, research and design.
Teams	6	4
Knowledge and skills (Mechanical)	Joining methods, mechanical principles, use of basic tools, forming, bending, steering layout and scaling.	Joining methods (more materials and bigger variety of joints), more advanced mechanic principles, use of tools, forming, bending, steering layout and scaling and cutting (different and variety of joints)
Innovation and creativity	Projects 1 and 2. Students received some scaffolding and were subjected to mini-lectures. Participants thereafter had a free hand regarding design and development.	Projects 3 and 4. Students received some scaffolding and were subjected to mini-lectures (**but less than in 2017**). Participants thereafter had a free hand regarding design and development
Knowledge and skills (Electrical)	Wire stripping, soldering and use of male and female connectors. Use of a multi-meter. Wiring diagrams, finding correct circuits.	Wire stripping, soldering and also the use of male and female connectors. Use of a multi-meter. Wiring diagrams (more detailed testing and more challenging to find correct layout).
Time	More or less 6 weeks	More or less 6 weeks
Team sizes	2 members (randomly selected)	2 or 3 members (select own team members)
Lecturer involvement	More or less 30%	Less than 20%

5.11 Cycle 2 - Intervention 2018

The second cycle in 2018 (see Table 5.9) was planned and conducted to serve as a follow-up of the first intervention and entailed another two projects, one mechanical

(Sterling engine) and one auto-electrical (starter charging system). The main purpose of this intervention was to implement hPBL in practical sessions and to introduce students to the next design cycle. Students again applied 7 hPBL steps in order to design, develop and complete the projects.

There was progression regarding knowledge and skills between the first two projects (1 and 2) and the last two projects (3 and 4) (see Table 5.8). The progression was established by means of an instructional scaffolding process as this should cause, according to Belland (2014), improved proficiency and higher-order thinking abilities.

The detail and planning of the application of the hPBL is shown in Table 5.9 and the detail of the individual projects are provided thereafter.

Table 5:9: Cycle 2 - intervention 2 - project 3 and 4 – 2018

2018 Intervention (2)

Week nr	Semester	Project	2 Groups 4 Teams: Team 1 (B4, A11, B2), Team 2 (B8, A1, B6)	2 Groups 4 Teams: Team 3 (A3, A5), Team 4 (B10, B12)
1	Semester 1 - 2018	Project 3-Sterling engine	Williamson's pre-test, research and problem exploration and planning	Williamson's pre-test, research and problem exploration and planning
2	Semester 1 - 2018	Project 3-Sterling engine	Design, project development and focus group interviews	Design sketches, project development and focus group interviews
3	Semester 1 - 2018	Project 3-Sterling engine	Project development, costing, testing and groupwork	Project development, costing, testing and groupwork
4	Semester 1 - 2018	Project 3-Sterling engine	Project development testing, groupwork and focus group interviews	Project development testing, groupwork and focus group interviews
5	Semester 1 - 2018	Project 3-Sterling engine	Project development, testing and groupwork	Project development, testing and groupwork
6	Semester 1 - 2018	Project 3-Sterling engine	Finalise project, groupwork and focus group meeting	Finalise project, groupwork and focus group interviews
7	Semester 1 - 2018	Project 4 -Wiring alternator	Rresearch and problem exploration and planning	Rresearch and problem exploration and planning
8	Semester 1 - 2018	Project 4 -Wiring alternator	Design, project development and focus group meeting	Design, project development and focus group meeting
9	Semester 1 - 2018	Project 4 -Wiring alternator	Project development, costing, testing and groupwork	Project development, costing, testing and groupwork
10	Semester 1 - 2018	Project 4 -Wiring alternator	Project development testing, groupwork and focus group meetings	Project development testing, groupwork and focus group meetings
11	Semester 1 - 2018	Project 4 -Wiring alternator	Project development, testing and groupwork	Project development, testing and groupwork
12	Semester 1 - 2018	Project 4 -Wiring alternator	Finalise project and Williamson's post test	Finalise project and Williamson's post test

5.11.1 Project 3: Mechanical - Sterling engine

* **Context:** Project 3 confronted students to build on the knowledge gained during the building of the "wire car" in project 2 as they had to design, plan and build a complete small model of a 'Sterling engine'. Students have very little knowledge regarding Sterling engines. However, they do have knowledge of 4-stroke and 2-stroke engines. **Note:** Less assistance will be provided by the lecturer and your responsibility will increase.

*** Scenario:** In this project, you need to build a unique model of a Sterling engine of your own design. Although all teams will receive various materials such as wire, aluminium, tins, wood, pipes, plastic and glue, you have to design a model of a Sterling engine regarding the layout, the shape, size, materials to use and scale to use. You will also need to provide materials not provided by the lecturer. The lecturer will provide less assistance than in projects 1 and 2, as he will only demonstrate how to use the applicable safety gear and tools needed for this project. You decide on all aspects of this project, however, the lecturer will provide a **minimum** of mini-lectures regarding the safety measures you need to adhere to. You have to find your own examples and information of Sterling engines. As each team can use a different design, they need to provide their own 'building material, however they will be provided some project information (resources), wire cutters, copper wire, solder, blow torch, crimping tool, paint, paper sheets and other equipment.

You now have the second opportunity to show how creative and innovative you are as you have a free hand in the design of this project. Use your imagination and feel free to do as much research of this topic as you like.

New skills such as working with and joining different materials were needed. Knowledge and understanding needed for project 3 were more accurate designing, bending, joining, soldering, measuring and assembling in order to complete the engine. Even the information that students needed to research during the planning stage was more comprehensive to access, arrange and select, as there are various ways of building a model of a Sterling engine.

Students worked in teams (2 to 3 members) and had to finish the project in ± six weeks. Each team completed one 'engine'.

*** PBL steps to follow**

Conceptualise (to understand what you need to do)

The team should then ensure you understand the problem by clarifying all relevant terms and concepts.

Define the problem (to fully understand the problem at hand)

Make sure you clearly understand and agree on the problem in order to fully define the problem (for example, what component should fit where, what material goes where, how does a Sterling engine work?). Discuss the problem content with your team members and come to an agreement, bearing all aspects in mind.

Identify knowledge and needs (brainstorm)

Identify current knowledge needed to solve the problem (for example, do I have any prior knowledge regarding engines, materials and joining?). Each member of the group expresses his or her opinion and ideas regarding the problem.

Categorise and structure ideas

It may be necessary to revisit previous steps. Identify tentative solutions to the problem. Discuss the possibilities from all angles (for example, there is more than one way to shape, join and make components). The lecturer will assist you by probing you with questions regarding different possibilities.

Formulate and identify learning objectives

Reach consensus regarding all facets of the problem. Decide what you need to do (outcomes) and clearly formulate your learning objectives. Compile a complete list and discuss possible dilemmas that may arise while addressing the problem and plan the next step.

Investigate, design and develop

Find appropriate sources, such as operating principles of heat engines and examples of a basic tin can Sterling engine, materials, cutting, bending and joining in your teams. Focus on the innovative design and development of a solution to the problem and finally develop the project.

Evaluate and reflect

Ensure that the objectives are aligned and assess each member's responsible involvement in the hPBL activities. Complete your project reports and submit a portfolio comprising all designs and relevant documents.

5.11.2 Project 4: Auto electrical system starter, alternator wiring system and ignition

***Context:** Students have some knowledge regarding auto-electrical components gained during project 1. However, they do not have knowledge of the more complicated electrical components used on ignition systems, alternators, chokes, fuel cut offs and ignition switches. This project (4) during the second intervention involved another auto-electrical project, where participants needed to plan, design, develop, assess and finalise. Students worked in teams with 2 to 3 members and they needed their prior theoretical and practical knowledge with regard to primary automotive electrical circuits to complete this project. **Note:** Less help will be provided by the lecturer and your responsibility will increase.

***Scenario:** In this project you need to connect the starter, circuit, solenoid system, charging system, choke system and idle cut-off and ignition switch on a stripped down, real engine in the workshop. Although all teams receive various materials such as conductors and connectors of different thickness and capabilities regarding Amps and load, you have to design the wiring to start and run a real engine. You do all testing, research, find examples and test connections to make the engine start with a key, run smoothly and charge the battery. The lecturer will provide less help than in projects 1, 2 and 3 as he will only demonstrate how to use the applicable safety gear and tools needed for this project. You should decide on all other aspects of the design and development and the lecturer will provide a **minimum** of mini-lectures regarding the safety measures you need to adhere to. You have to search for and evaluate information on this project.

* PBL steps to follow:

Conceptualise (to understand what you need to do)

The team should then ensure that all members understand the problem by clarifying all relevant terms and concepts.

Define the problem (to fully understand the problem at hand)

Ensure you clearly understand and agree on the problem in order to fully define it (for example, which component does what?). Discuss the problem content with your team and agree to a general problem understanding.

Identify knowledge and needs (brainstorm)

Identify current knowledge and learning needed to solve the problem (for example, do you have any prior knowledge regarding auto electrical systems?). Each member of the group should express his or her opinion and ideas regarding the problem.

Categorise and structure ideas

It may be necessary to revisit previous steps. Identify tentative solutions to the problem. Discuss the possibilities from all angles (for example, there is more than one way to test and connect the circuits). The lecturer will assist you by probing you with questions regarding different possibilities. Discuss tentative steps to be taken to solve the problem.

Formulate and identify learning objectives

Reach consensus regarding all facets of the problem. Decide what you need to do (outcomes) and clearly formulate your learning objectives. Compile a complete list of possibilities and discuss possible dilemmas that may arise while solving the problem and plan the next step (for example, what do you need to know regarding electrical circuits?).

Investigate, design and develop

Find appropriate sources, such as electrical starter systems, alternator circuits, choke, ignition and distributors. Focus on the innovative design and development of a solution to the problem. Connect electrical cables to the components and finally test all components.

Evaluate and reflect

Ensure that the objectives are aligned and assess each member's responsible involvement in the hPBL activities. Complete your project reports and submit a portfolio compromising all design and relevant documents.

Once again, there were two weekly group sessions (interviews) and at the end of ± six weeks, students were randomly selected for the semi-structured interviews. Teams also kept project sheets that were updated weekly (see Addendum O). The interviews were transcribed verbatim and included in the qualitative data (see chapter 6).

5.12 Conclusion

Chapter 5 provided an overview of the research design, methodology and interventions. The overview includes information regarding the research paradigm, the methods of quantitative and qualitative data collection and data analyses, reliability, trustworthiness and ethics. The overview also describes the role of the researcher, DBR the intervention detail and project development. In chapter 6 the data analysis and research results are discussed.

CHAPTER 6: DATA ANALYSIS AND RESEARCH RESULTS

6.1 Introduction

The purpose of this chapter is to report on the data analyses of the quantitative and qualitative results of MT students in order to investigate the research questions.

6.2 Research questions

The main research question was: How can the implementation of hybrid problem-based learning in Mechanical Technology enhance pre-service teachers' self-directed learning?

The sub-questions were the following:

1. What does Mechanical Technology, problem-based learning and self-directed learning entail?
2. How can the implementation of hybrid problem-based learning in Mechanical Technology enhance pre-service teachers' higher-order thinking, practical knowledge and skills in the automotive discipline?
3. To what extent can pre-service Mechanical Technology teachers enhance their self-directed learning in a problem-based context?

6.3 Biographic information and participants

Biographical information of participants is presented in Table 6.1. The cohort consisted mainly of male participants from one race group, however there were also three females of which one was from a different race and culture.

Table 6:1: Biographic information of participants

2017 (Intervention 1)	
Age	20 – 24 years
Gender	Male 9 Female 3
Number	12
Language	Afrikaans 9 English 3
2018 (Intervention 2)	
Age	20 – 25 years
Gender	Male 7 Female 3
Number	10
Language	Afrikaans 7 English 3

To our knowledge, the NWU is the only university offering the specialised MT and MTA education for teacher students in South Africa. As only a small number of students enrolled for the modules VTEE 222 and VTEE 312, the population thus comprises one cohort of 12 students (however, at the end of 2017 two students cancelled their studies, with the remainder of 10 students to continue in 2018). Therefore, only 10 students completed the two pre- and two post-questionnaires in 2018. In total (2017 and 2018) 44 responses were used for the quantitative research.

6.4 Quantitative data analysis

Descriptive statistics were used in this quantitative analysis as this method is, according to Leedy & Ormrod (2013), a deductive method suitable to describe, interpret and explain data obtained from small group of students. Although the help of the Statistical Consultation Services of North-West University was called on, most of the work in chapter six was done by the researcher.

The instrument used in this study was the Williamson's SRSSDL questionnaire and the five broad areas of self-directed learning focussed on in the SRSSDL are displayed in Figure 6.1. Question 1-7 involved biographical information.

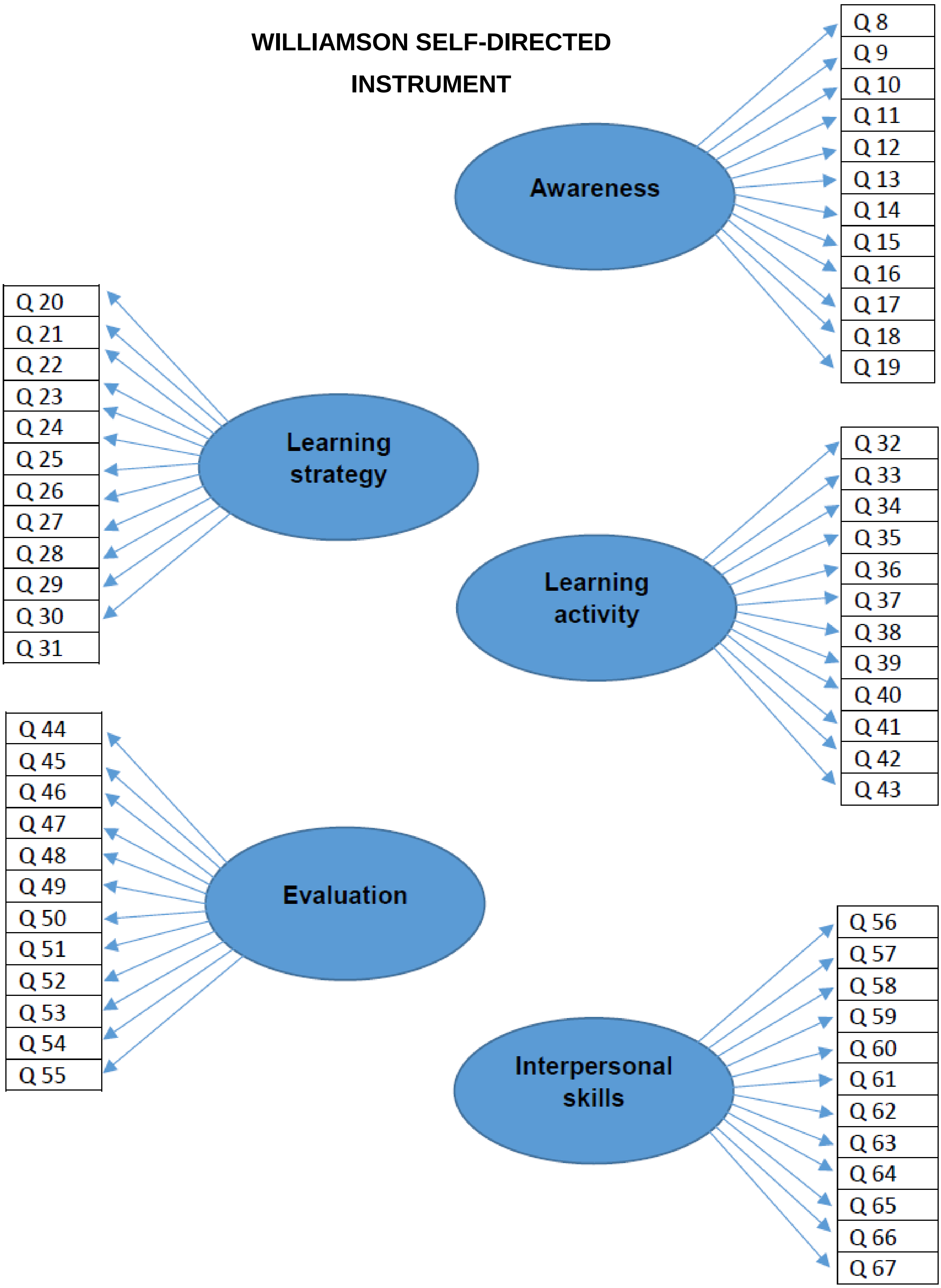


Figure 6:1: Five broad areas of self-directed learning

Source: Compiled by researcher

Results of the Williamson SRSSDL questionnaire are outlined according to each construct in the following subsection. Results of 2017 and 2018 are included in each construct (pre- and post-tests).

6.4.1 Awareness construct

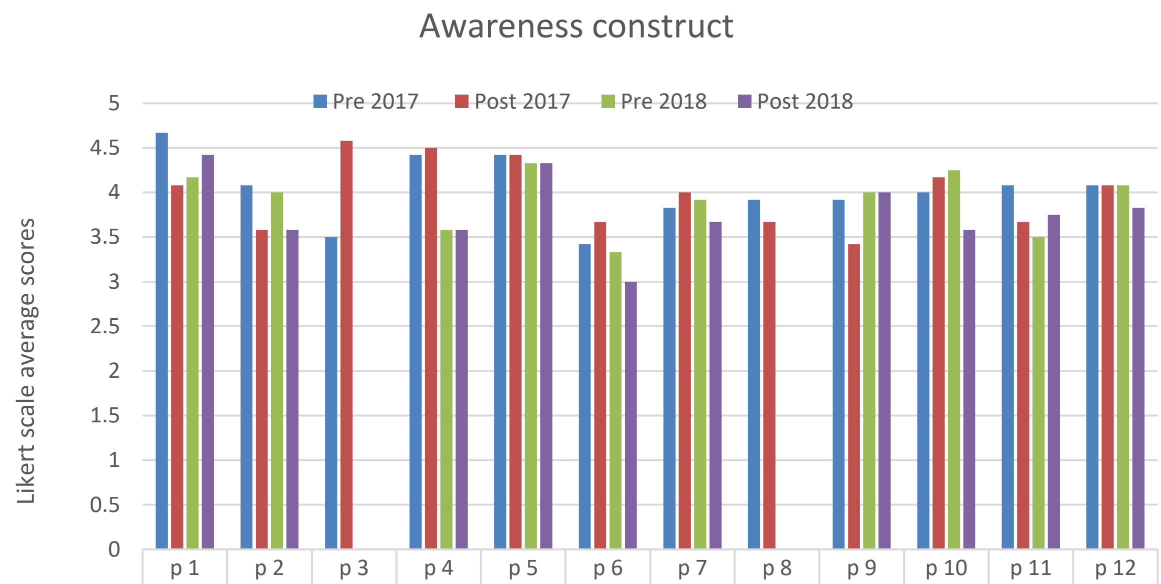
6.4.1.1 Results 2017

*Please note that the percentages have been rounded off.

For each individual participant, the average values for awareness are displayed in Figure 6.2. The SRSSDL scores of Participants 1, 2, 8, 9 and 11 (42% of the population) revealed that they rated themselves lower in the post-test than in the pre-test. The awareness construct scores of Participants 5 and 12 (16%) indicated *no increase* or decrease in self-directed readiness. However, Participant 3 (who only participated in 2017) and Participants 4, 6, 7 and 10 experienced a small (but noticeable) increase in their awareness during the first intervention in 2017. Therefore, by developing the two projects in 2017, Participants 3, 4, 6, 7 and 10 (42% of the population) improved their self-directed awareness in a small, but perceptible way.

6.4.1.2 Results 2018

In 2018 a similar tendency was noticed as the awareness average scores of Participants 2, 6, 7, 10 and 12 (50%) reflected a decrease in self-directed readiness as participants rated themselves higher at the beginning than at the end of the intervention. The scores of Participants 4, 5 and 9 (30%) reflected a *no change* tendency regarding the awareness construct. The positive part is that the awareness construct scores of Participants 1 and 11 (20%) increased after the post-test in 2018 (see Figure 6.2).



	p 1	p 2	p 3	p 4	p 5	p 6	p 7	p 8	p 9	p 10	p 11	p 12
Pre 2017	4.67	4.08	3.5	4.42	4.42	3.42	3.83	3.92	3.92	4	4.08	4.08
Post 2017	4.08	3.58	4.58	4.5	4.42	3.67	4	3.67	3.42	4.17	3.67	4.08
Pre 2018	4.17	4	0	3.58	4.33	3.33	3.92	0	4	4.25	3.5	4.08
Post 2018	4.42	3.58	0	3.58	4.33	3	3.67	0	4	3.58	3.75	3.83

Figure 6:2: Average scores of awareness construct 2017 and 2018 pre- and post-test.

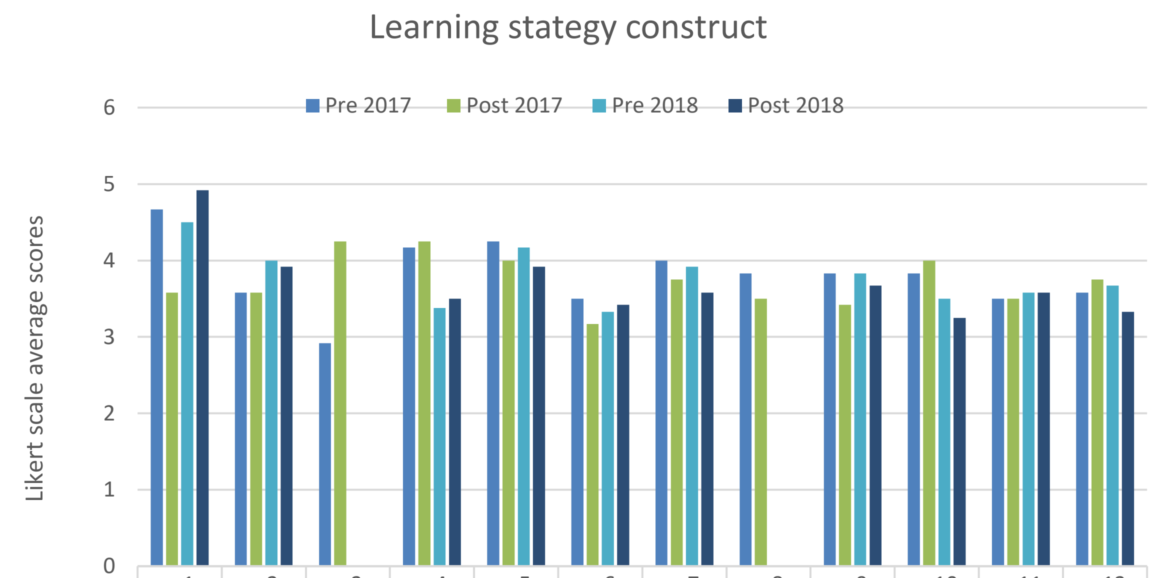
6.4.2 Learning strategy construct

6.4.2.1 Results 2017

Figure 6.3 represents the learning strategy construct. Participants 1, 5, 6, 7, 8 and 9 (50% of the participants) indicated a decrease in this construct as their scores declined from the pre-test to the post-test in 2017. Participants 2 and 11 (17%) indicated *no change* in self-directed readiness regarding this construct. However, Participants 3, 4, 10 and 12 (33%) reflected an increase regarding the learning strategy construct (see Figure 6.3).

6.4.2.2 Results 2018

In 2018 Participants 2, 5, 7, 9, 10 and 12 (60% of the remaining 10) revealed that their self-directed readiness regarding learning strategy decreased. Participant 11 (10%) did not indicate any increase or decrease of his self-directed readiness regarding the learning strategy construct. Nonetheless, Participants 1, 4 and 6 (30%) revealed a slight, but noteworthy increase in the learning strategy construct (see Figure 6.3).



	p 1	p 2	p 3	p 4	p 5	p 6	p 7	p 8	p 9	p 10	p 11	p 12
Pre 2017	4.67	3.58	2.92	4.17	4.25	3.5	4	3.83	3.83	3.83	3.5	3.58
Post 2017	3.58	3.58	4.25	4.25	4	3.17	3.75	3.5	3.42	4	3.5	3.75
Pre 2018	4.5	4	0	3.38	4.17	3.33	3.92	0	3.83	3.5	3.58	3.67
Post 2018	4.92	3.92	0	3.5	3.92	3.42	3.58	0	3.67	3.25	3.58	3.33

Figure 6:3: Average scores of learning strategy construct 2017 and 2018 pre- and post-test

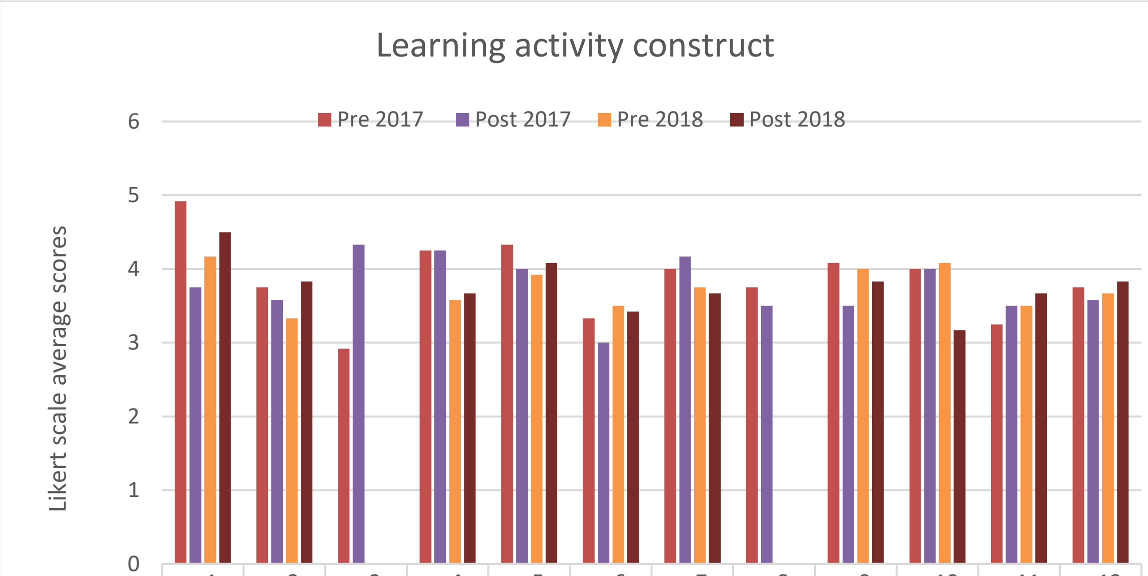
6.4.3 Learning activity construct

6.4.3.1 Results 2017

In Figure 6.4, the average scores of the learning activity construct are displayed. Participants 1, 2, 5, 6, 8, 9 and 12 (58% of the population) rated themselves lower after the post-test in 2017. Participants 4 and 10 (17%) did not indicate any increase regarding the learning activity construct. However, Participants 3, 7 and 11 (25%) experienced a small (but noticeable) increase in their self-directed readiness in the learning activity construct from the pre-test to the post-test (see Figure 6.4).

6.4.3.2 Results 2018

In 2018 a similar tendency was noticed in the learning activity average scores of Participants 6, 7, 9 and 10 (40%) as it reflected a decrease from pre-test to post-test. No participants had a no change experience. Nerveless, the learning activity average scores of Participants 1, 2, 4, 5, 11 and 12 (60%) increased after the post-test in 2018 (see Figure 6.4).



	p 1	p 2	p 3	p 4	p 5	p 6	p 7	p 8	p 9	p 10	p 11	p 12
Pre 2017	4.92	3.75	2.92	4.25	4.33	3.33	4	3.75	4.08	4	3.25	3.75
Post 2017	3.75	3.58	4.33	4.25	4	3	4.17	3.5	3.5	4	3.5	3.58
Pre 2018	4.17	3.33	0	3.58	3.92	3.5	3.75	0	4	4.08	3.5	3.67
Post 2018	4.5	3.83	0	3.67	4.08	3.42	3.67	0	3.83	3.17	3.67	3.83

Figure 6:4: Average scores of learning activity construct 2017 and 2018 pre- and post-test

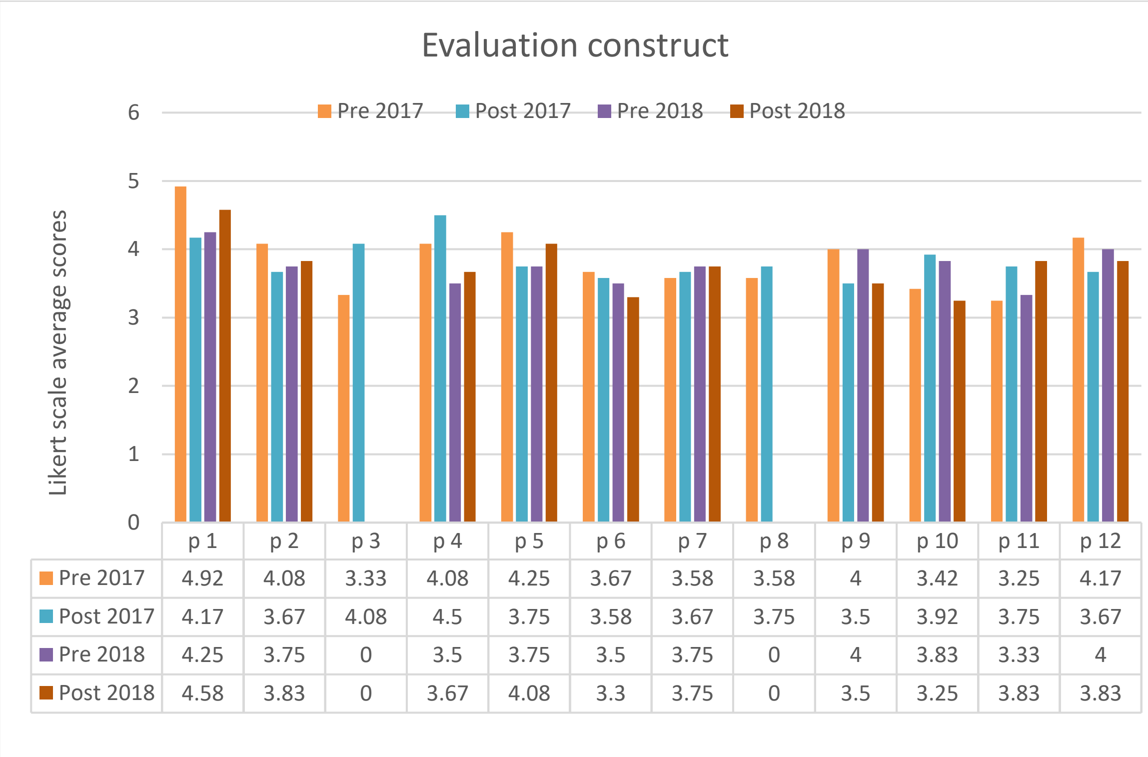
6.4.4 Evaluation construct

6.4.4.1 Results 2017

Figure 6.5 represents the evaluation construct. Participants 1, 2, 5, 6, 9 and 12 (50% of the participants) indicated a decrease of their self-directed readiness as their scores declined from pre-test to post-test in 2017. However, Participants 3, 4, 7, 8, 10 and 11 (50%) reflected on their SRSSDL scores that they increased their self-directed readiness regarding the evaluation strategy construct from pre-test to post-test (see Figure 6.5).

6.4.4.2 Results 2018

In 2018 Participants 6, 9, 10 and 12 (40%) indicated that their self-directed readiness regarding the evaluation construct decreased. Only Participant 7 (10%) did not indicate any increase regarding the evaluation construct. Nonetheless, Participants 1, 2, 4, 5, and 11 (50%) revealed by means of their scores a slight, but noteworthy increase of the evaluation construct (see Figure 6.5).



	p 1	p 2	p 3	p 4	p 5	p 6	p 7	p 8	p 9	p 10	p 11	p 12
Pre 2017	4.92	4.08	3.33	4.08	4.25	3.67	3.58	3.58	4	3.42	3.25	4.17
Post 2017	4.17	3.67	4.08	4.5	3.75	3.58	3.67	3.75	3.5	3.92	3.75	3.67
Pre 2018	4.25	3.75	0	3.5	3.75	3.5	3.75	0	4	3.83	3.33	4
Post 2018	4.58	3.83	0	3.67	4.08	3.3	3.75	0	3.5	3.25	3.83	3.83

Figure 6:5: Average scores of *evaluation* construct 2017 and 2018 pre- and post-test

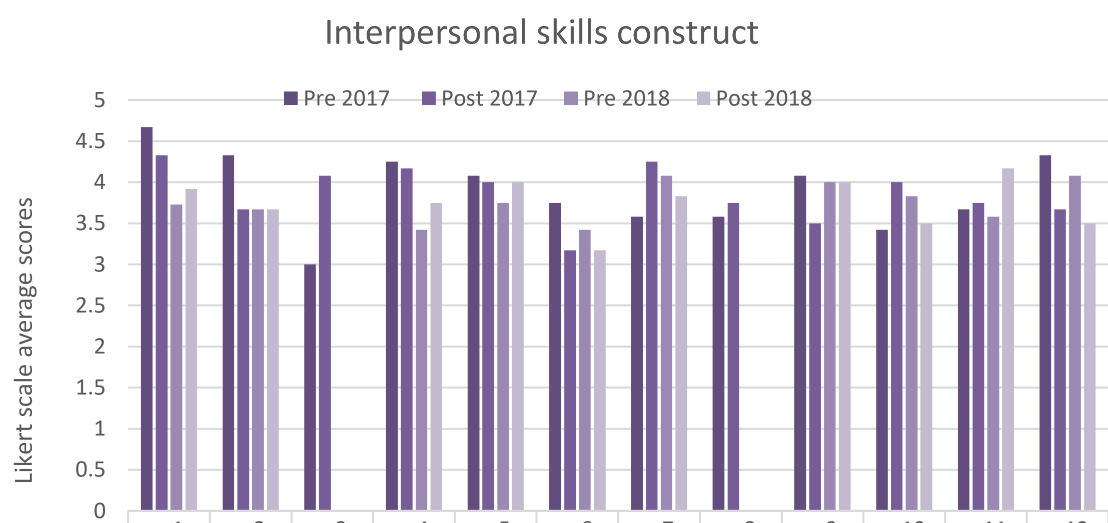
6.4.5 Interpersonal skills construct

6.4.5.1 Results 2017

Figure 6.6 represents the interpersonal skills construct. Participants 1, 2, 4, 5, 6, 9 and 12 (58% of the participants) indicated, by means of their scores for the interpersonal skills, a decrease of their self-directed readiness scores from the pre- to post-test 2017. However Participants 3, 7, 8, 10 and 11 (42%) reflected an improvement on their SRSSDL interpersonal skills construct (see Figure 6.6).

6.4.5.2 Results 2018

During the second intervention in 2018, Participants 6, 7, 10 and 12 (40%) indicated that their self-directed readiness regarding the interpersonal construct decreased. Participants 2 and 9 (20%) did not indicate any increase or decrease regarding the interpersonal construct. Nonetheless, Participants 1, 4, 5 and 11 (40%) revealed, by means of their scores of the interpersonal construct, that they had a slight, but noteworthy increase of self-directed readiness (see Figure 6.6).



	p 1	p 2	p 3	p 4	p 5	p 6	p 7	p 8	p 9	p 10	p 11	p 12
Pre 2017	4.67	4.33	3	4.25	4.08	3.75	3.58	3.58	4.08	3.42	3.67	4.33
Post 2017	4.33	3.67	4.08	4.17	4	3.17	4.25	3.75	3.5	4	3.75	3.67
Pre 2018	3.73	3.67	0	3.42	3.75	3.42	4.08	0	4	3.83	3.58	4.08
Post 2018	3.92	3.67	0	3.75	4	3.17	3.83	0	4	3.5	4.17	3.5

Figure 6:6: Average scores of *interpersonal skills* construct 2017 and 2018 pre- and post-test

During 2017, there was a noticeable decline regarding self-directed readiness as the scores for each construct, indicated that participants experienced a decrease regarding their SRSSDL scores. Regarding a *no change* status for all five constructs, the scores were 2 for each construct. However, some participants did indicate an improvement regarding their self-directed readiness.

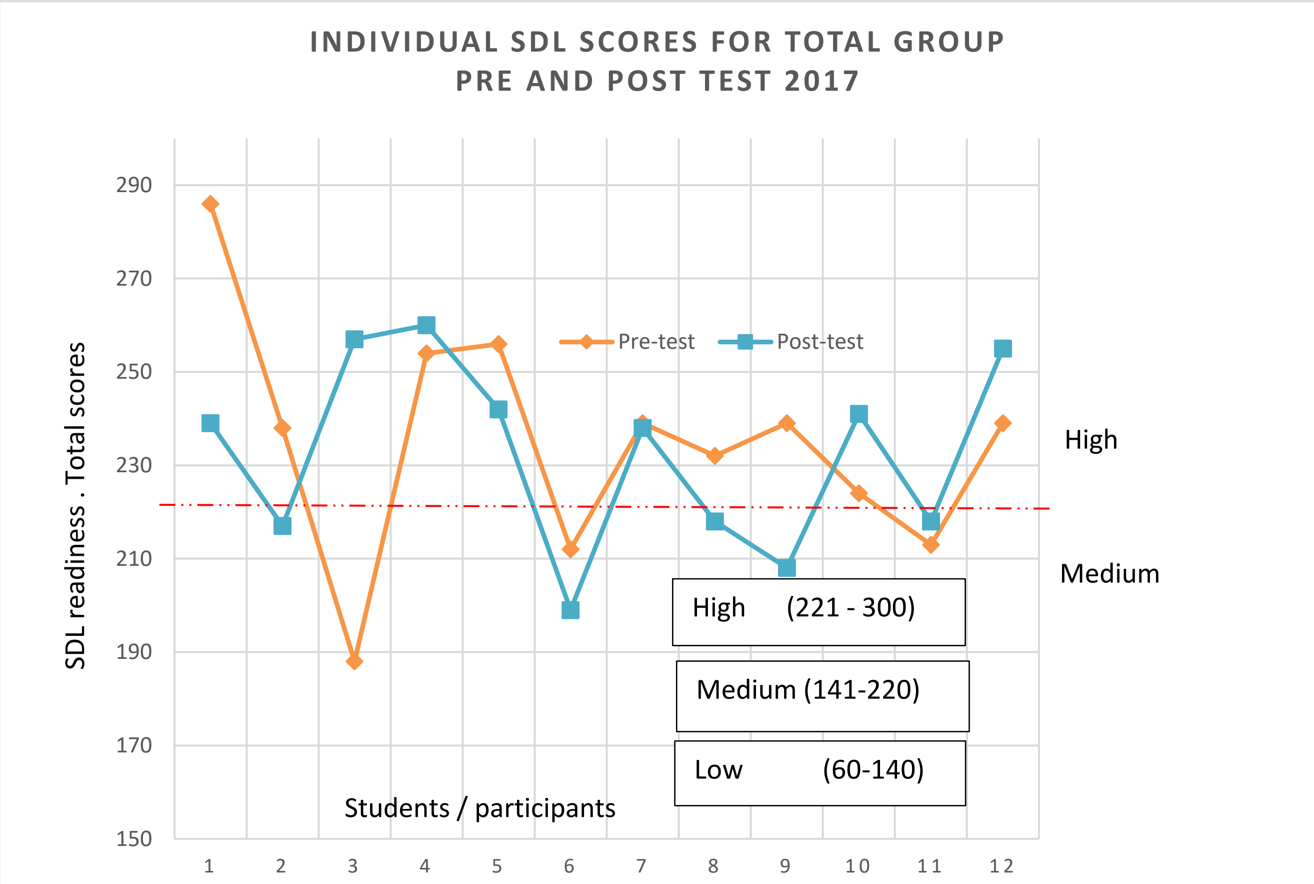
During the intervention in 2018, some scores for the five constructs regarding the participants revealed that they did not experience a decrease or increase in self-directedness. However, a number of participants did increase their scores from pre-test 2 to post-test 2 as a result of the second round of the hPBL intervention.

The next step in the analyses of the quantitative results entailed the totalling of all individual scores of the options on the Likert scale of the Williamson's questionnaire. The results thereof are displayed in Figures 6.7 and 6.8.

6.4.6 Results of self-directed learning total scores

The totals of all scores for each individual SRSSDL construct for each student for 2017 and 2018 were tallied and the results are shown in Figures 6.7 and 6.8 (see Table 5.1). According to Williamson (2007) a scoring range between 221 and 300 indicates high SDL capabilities, scores between 141 and 220 are considered moderate and scores between 60 and 140 are considered a low SDL rating. The red dotted line running through the graph represents the division between high scores and moderate scores (see Figures 6.7 and 6.8). Thus, all dots above the red dotted line represent a high individual SDL score. Note that nine participants had above average (above 220) scores for the pre-test and seven for the post-test. Even though six participants (P1, P2, P5, P6, P8 and P9) showed a decrease in their total scores from the pre-test to the post-test, five participants (P3, P4, P10, P11 and P12) showed an increase in the scores from pre-test to post-test. Thus 50% of the participants experienced a decrease, 42% an increase and 8% showed no change.

The first group *(SDL decreasing)* started with the projects in 2017 with an average SDL readiness score of 243, which is according to Williamson 'high' (see Table 5.2) and the second group *(SDL increasing)* started the intervention in 2017 with an average total score of 223 that is according to Williamson still high (See Table 5.1). Thus, the intervention could have a positive effect regarding the enhancement of SDL readiness of 42% of the class during 2017.



	1	2	3	4	5	6	7	8	9	10	11	12
Pre-test	286	238	188	254	256	212	239	232	239	224	213	239
Post-test	239	217	257	260	242	199	238	218	208	241	218	255

Figure 6:7: Individual SDL total scores for 2017

In Figure 6.8, representing the total scores for 2018, the dotted red line again shows the dividing line between moderate and high self-directed learning total scores implicating high total scores of all participants above 220. Note the absence of the numbers 3 and 10 on the x-axis that represent the two students who did not participate in 2018. For the pre-test, seven participants had high scores and for the post-test, five had high scores. When looking for an increase or decrease regarding pre- to post-test it was found that five participants (P1, P5, P6, P7 and P9) decreased their scores from pre- to post-test and three participants (P4, P10 and P12) increased their scores, while two participants (P2 and P11) experienced no change in scores.

Therefore, during the 2018 intervention, 70% of the participants started (pre-test), their projects with high (above 220) total scores and 60% of them ended (post-test) their intervention with high total scores. Individual scores revealed a 50% decrease in SDL from pre- to post-test and 30% experienced an increase. 20% of the participants was unaffected by the intervention as their scores did not change.

Thus, in 2017, 42% of the participants increased their SDL and in 2018, 20% increased their SDL (see Figure 6.8).

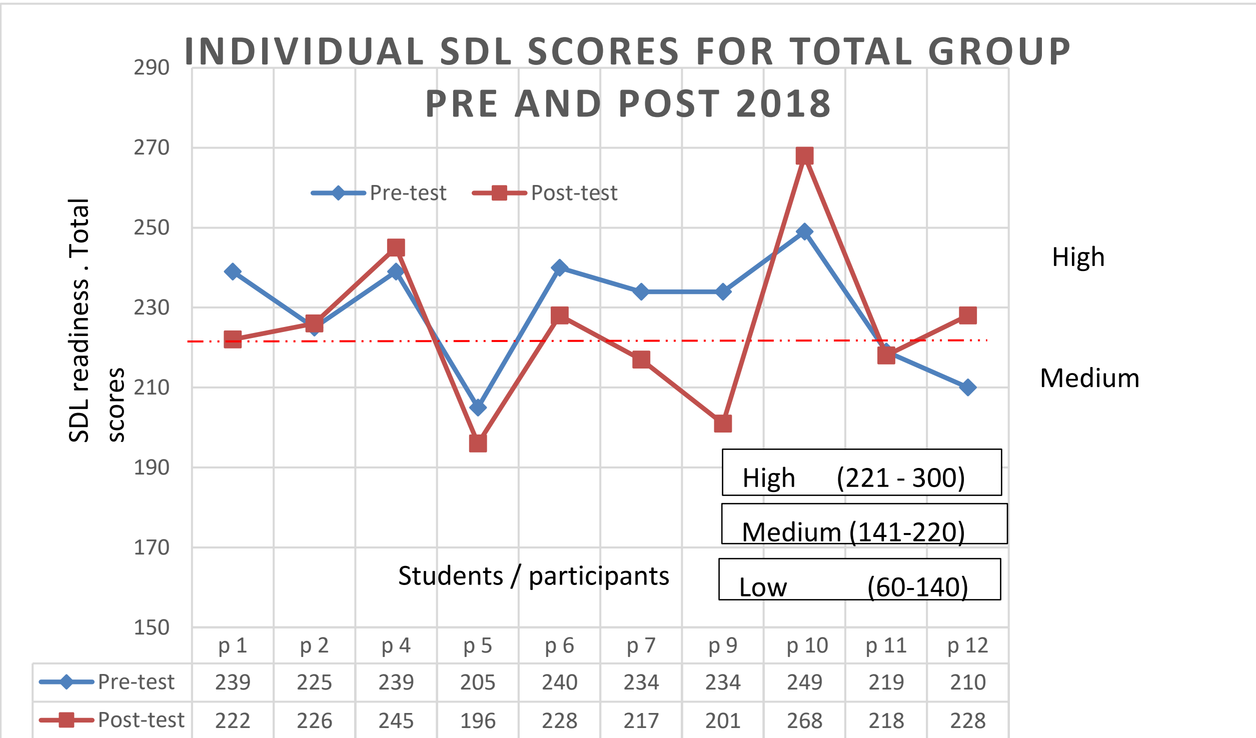


Figure 6:8: Individual SDL total scores for 2018

Although it seems as though Participants P1 and P9 experienced many challenges with the hPBL tasks with regards to their SDL, the SDL total scores corresponds with the findings found in the literature. For example, Lee *et al.* (2010) found that PBL could in most instances enhance the SDL of students, however, they stated that PBL does not guarantee an improvement in their SDL. Chakravarthi and Vijayan (2010) found that PBL might, enhance SDL, however, it is not always to the same extent.

6.4.7 Results of the mean, MSE and variance

The mean, mean squared error (MSE) and variance are displayed in Table 6.2 and discussed thereafter.

The mean squared error (MSE) is used to estimate the average of the squares of the errors or the average squared difference between the estimated values and what is being estimated (Wang & Bovik, 2009).

Table 6:2: Means and MSE

Construct	Mean values				
	Pre-test 2017	Post-test 2017	Pre-test 2018	Post-test 2018	MSE
Awareness	4,010	4,000	3,980	3,840	0,075
Learning strategies	3,860	3,770	3,870	3,720	0,106
Learning activities	3,890	3,800	3,770	3,750	0,129
Evaluation	3,840	3,840	3,850	3,800	0,096
Interpersonal skills	4,000	3,990	3,800	3,770	0,095
TOTAL	**235,19**	**231,55**	**231,04**	**226,47**	

As can be derived from Table 6.2, there was a slight decline in mean values between 2017 and 2018. According to Filzmoser *et al.* (2009), having low MSE scores is good and a score close to zero is even better. MSE is a safe method of validation in small sample groups. These results are interpreted in the next section.

6.5 Interpretation of the quantitative research

As can be seen in previous figures and tables, more students enhanced their SDL skills in 2018 than in 2017 regarding the learning activity and evaluation construct, while the interpersonal skills construct stayed the same. It thus seems that participants experienced challenges specifically with regard to the awareness and learning strategies constructs during 2018.

Figures 6.2 to 6.8 as well as Table 6.2 indicate a decline in SRSSDL construct scores. This can probably be as a result of students rating themselves unrealistically high at the start of both interventions, that students underrated the PBL process, underestimated the projects or overrated their own abilities. There was a general decline in mean values between 2017 and 2018 that can possibly be that students thought they were self-directed after the 2017 intervention. Students maybe thought that the projects would be easy, some students lost interest somewhere during intervention one and two, or the intervention was too difficult and too time consuming. The decline could also be linked to the more *complex nature* of projects 3 and 4, the decrease in lecturer involvement and the fact that students were too confident when they started project 3 and 4. Although the value of the four projects may seem insignificant, the positive effect regarding the enhancement of some participants' SDL should not be overlooked, as some students did indeed improve their self-directedness in some SRSSDL constructs.

When looking at Figure 6.7 and 6.8 it can be derived from the total scores, that some of the students participating in the 4 projects did indeed improve their self-directedness. Although few students reflected no change and others reflected a decrease in their self-directedness, one should not underestimate the improvement in SDL. Although this improvement in self-directedness concurs with the SRSSDL construct's findings and with the findings in the literature, it does not concur with the means findings. The researcher is of opinion that the discrepancy described above can be contributed to the small sample size.

To summarise, results from Figures 6.2 - 6.8 as well as Tables 6.2 indicate that individual participants slightly increased, decreased or have had similar values regarding all five the SDL constructs during both PBL interventions. However, it should be noted that most of the participants had a high SDL score at the beginning of the PBL intervention (above 220) since a high SDL score, according to Williamson (2007) is between 221 and 300.

Mentz and van Zyl (2016) had similar results when using small groups in a cooperative setting. They also used Williamson's questionnaire and mentioned that "a decrease was noted in all categories of those students with a high SDL score, however all the scores were still in the high category" (Mentz & van Zyl, 2016:90). They mentioned that the decrease in high SDL scores could be a result of students who worked together in cooperative groups whereas they were used to working on their own. Similarly, PBL requires students to cooperate when working on open-ended problems or challenges. As the intervention in 2017 was students first experience with PBL and group work, this was rather a challenging task. All participants should take responsibility for their own learning as well as their peers during project development. Further, students could overestimate or underestimate themselves in terms of their self-directed ability and responsibility in learning. Findings from the qualitative data could further explain students' personal and group experiences with PBL during both project interventions.

6.6 Qualitative data analysis

The qualitative data (2017 and 2018) comprises of focus group interviews/meetings, weekly project sheets, individual interviews as well as the lecturers' observations and narratives (see Tables 5.4 and 5.5).

The qualitative data consisted of pictorial and written evidence of the two cycles of design that were conducted during 2017 and 2018. In this subsection, evidence of project design and development are included as each of the projects are outlined. One example of each project is tabulated with pictorial evidence, design, development as well as feedback regarding participants experiences.

6.6.1 Examples of PBL activities

Project 1 consisted of the development of an electrical wiring system (see Section 5.10.1 and Table 6.3, project 2 consisted of the development of an artefact (wire cart) (see Section 5.10.2 and Table 6.4, project 3 involved the development of a Sterling engine (see Section 5.11.1 and Table 6.5) and project 4 consisted of the development of a more complex wiring system (see Section 5.1.2 and Table 6.6).

Table 6:3: Project 1 – design and development of a wiring system (2017)

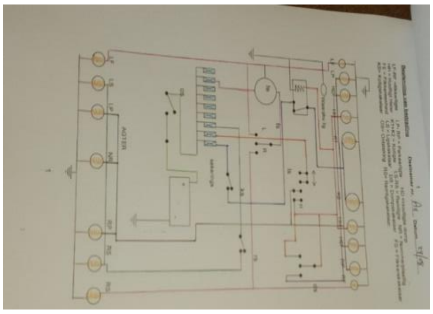
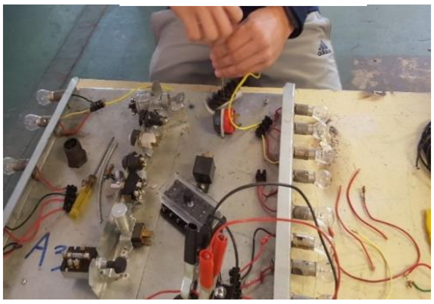
Project 1	Students' exemplars
Design 	**1. What is your experience with the project?** *A1 "Not as easy as it looked. It is more complicated than we thought, but it was nice."* **2. Which facet do you like the most?** *A5 "Learning what you did not know before."* **3. Have you noticed anything that you will do differently when you develop such a project again?** *B12 "… to think before you start working."* **4. What is your experience of working in a group?** *B4 "We had to accept each other and sort out our differences."*
Development 	**5. Is one of you in charge of the team?** A1 "*No, we are together in this."* **6. What problems have you experienced?** *A4 "To sort out our differences of opinion."* **7. Do you get along, or is there conflict? If so, how do you handle it?** *A3 "We had to accept each other and sort out our differences."*
Development 	**8. How do you share responsibilities?** *A3 "… we had to accept the responsibilities and share it evenly."* **9. Did you have any differences regarding your working and thinking methods?** *A7 "Not really, we worked well together and made good progress."* **10. What have you achieved today?** *B10 "We did what we planned to do, so we are satisfied with what we did, the planning is done."*
Final project 	• **Development of higher-order thinking and SDL** **Higher order thinking:** *"…as you work and start building, you get other ideas that work better." "It is complicate." "…not as easy as we anticipated".* **Practical skills:** "*…we could see it and do it myself, I understand better". "We battled to do it".* **SDL skills:** *"By interacting with each other." "… we needed each other, two is better than one".*

Table 6:4: Project 2 – design and development of wire car (2017)

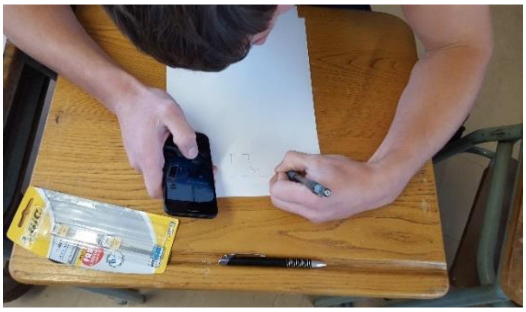
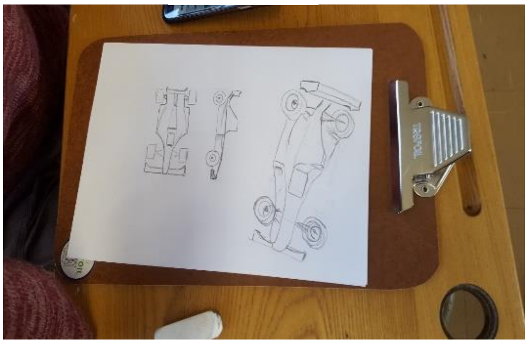
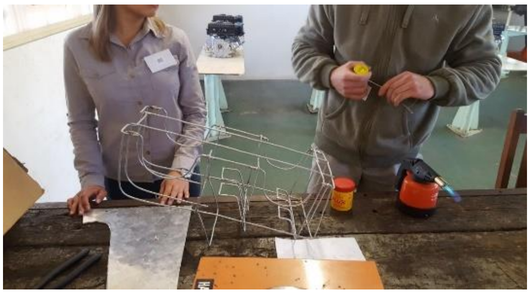
Project 2	Students’ exemplars
Design  Design  Development  Final artefact 	**1. What is your experience with the project?** *B6 “It is very nice to plan your own work.”* **2. Which facet do you like the most?** *B6 “The soldering work.”* **3. You are currently working on B6's car. Have you noticed anything that you will do differently when you develop another car?** *B8 “Yes, fewer joints.”* **4. What is your experience of working in a group?** *B2 “Group work is very effective.”* **5. Is one of you in charge of the team?** A9 “*No, we both work together.”* **6. What problems have you experienced?** *A11 “The wire is very hard and hard to bend, but we have solved the problem.”* **7. Do you get along, or is there conflict? If so, how do you handle it?** *A3 “We talk about it and sort it out quickly. The work must be done.”* **8. How do you share responsibilities?** *A7 “We soon found out who is good at what. We immediately saw that I was fine with the 90 ° bending and he had the larger bending work.”* **9. Did you have any differences regarding your working and thinking methods?** *A1 “Yes, we did as B6 is not concerned with precision and accuracy where B8 is a perfectionist. We had to make compromises to progress.”* **10. What have you achieved today?** *A5 “Our finishing touches, we know how to do everything, so we work faster now.”* • **Development of higher-order thinking and SDL** **Higher order thinking:** “Learning what I did not know*”.”I have never done something like this”.”The steering system was very difficult”.* **Practical skills:** “*…be creative”. “I did not know I can do this”.* **SDL skills:** *“…we shared the load and the responsibilities.”*

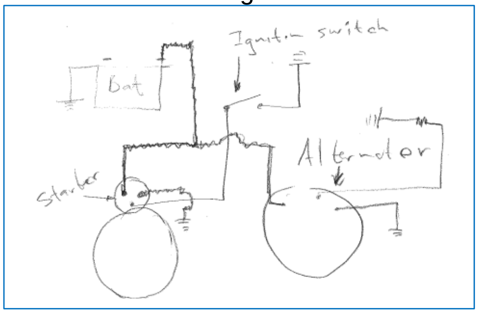
Table 6:5: Project 3 – design and development of Sterling engine (2018)

Project 3	Students' exemplars
Design  Development  Development  Final artefact 	**1. What is your experience with the project?** *B10 "*It was nice. When done it will be even nicer and then we will see the utility of it.*"* **2. Which facet do you like the most?** *B12 "Putting everything together and watching it develop into something … We are looking forward to the end. We looked at videos to get ideas."* **3. Have you noticed anything that you will do differently when you develop such a project again?** *B12 "We did better research this time. I went to look at models of the engines and then I designed my own one with a combination of what I found in my research."* **4. What is your experience of working in a group?** *B12 "We communicated well. We shared ideas."* **5. Is one of you in charge of the team?** *A1"I think I am, in this part of the project. Because I understand better."* **6. What problems have you experienced?** *B8 "We experienced no conflict – we worked well together."* **7. Do you get along, or is there conflict? If so, how do you handle it?** *A3 "We talk to each other and sort it out. We will handle it professionally."* **8. How do you share responsibilities?** *B6 "Yes we had to accept the responsibilities and share it 50/50."* **9. Did you have any differences regarding your working and thinking methods?** *A11 "Yes we did, but then we relaxed for a few minutes. We apologise. We talk. We go on."* **10. What have you achieved today?** *B10 "We fell behind a bit. We soon found confidence to work faster."* • **Development of higher-order thinking and SDL** **Higher order thinking:** *"We did more complicated work than last year." "This was very hard". We had to plan and re-plan".* **Practical skills:** "*Some components were very tricky."* **SDL skills:** *"Mostly we share all together."*

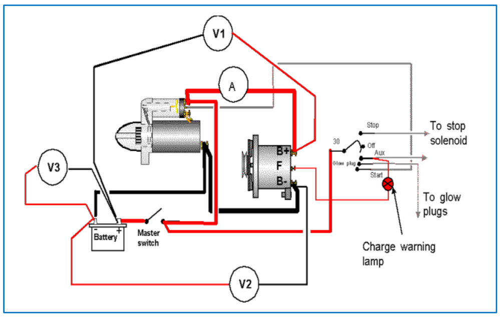
Table 6:6: Project 4 – design and development of Alternator wiring (2018)

<table>
<tr><th>Project 4</th><th>Students’ exemplars</th></tr>
<tr><td>

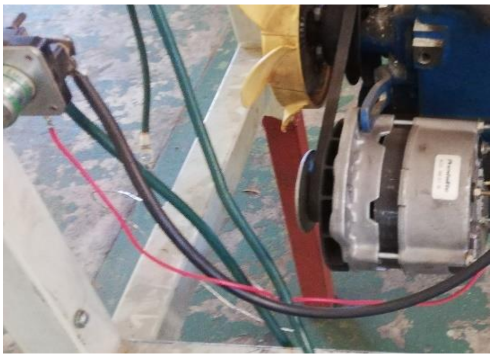
Design



Design



Development



Final project

</td><td>

1. What is your experience with the project?
B6 “We took it calmly and did not over-react. I have never heard of this before.”

2. Which facet do you like the most?
B4 “The ‘self-do’ part. Waiting to see if it will work.”

3. Have you noticed anything that you will do differently when you develop such a project again?
A1“Not much. Maybe do more research.”

4. What is your experience of working in a gro*up?*
B4 “It is great. We loved it.”

5. Is one of you in charge of the team?
A1 “We don’t really know.”

6. What problems have you experienced?
A4 “Not so to mention. Small hiccups here and there. Some components were very tricky.”

7. Do you get along, or is there conflict? If so, how do you handle it?
A3 “There was not any need. Only small incidents which we quickly resolved.”

8. How do you share responsibilities?
A5 “We both do. Share and share alike.”

9. Did you have any differences regarding your working and thinking methods?
A1 “The female was a bit dominant (smile.)”

10. What have you achieved today?
B10 “We had a positive experience and we learned a lot”

- **Development of higher-order thinking and SDL**

Higher order thinking: *“It is hard to figure it out.” “There are so many wires, not easy to figure out”.*

Practical skills: “*…we could test the voltage of the alternator”. “…we did not know where to start”.*

SDL skills: *“…but we mostly managed.”*

</td></tr>
</table>

6.6.2 Researchers remarks

During the project development stages, the lecturer moved between teams to observe and compiled a list with his own comment regarding the projects. These are listed below in Tables 6.7.

Table 6:7: Researcher's remarks 2017 and 2018

2017	* PBL and project work seems to be effective in this practical module as students work enthusiastically and reflect positively thereon. * Mastering new skills seems to keep students interested and motivated. * Working on projects are part of the development process as new innovative ideas arise from solving problems.
	* Group work seems to be effective in this intervention. * Sharing responsibilities and liabilities developed spontaneously when working in a cooperative environment. * Problems are solved while developing projects.
	* Taking responsibility for sharing the workload and working out differences was also important in order to complete the project. * By assigning work responsibilities according to individual skills and abilities, it improved the product and streamlined the process.
	* PBL enhanced the ability to work in one team even when personalities differ widely. * Students felt they have accomplished their initial goals by applying prior knowledge to solve the problem and finish the product.
2018	* Problems are solved, but some help is needed. * Group work seems to be working well, especially as they chose their own partner/s. * Sharing responsibilities developed some conflict when difficult parts were done. * It was also important to share the workload and work out differences to complete the project. * This project was difficult, but individual skills and abilities improved. * PBL enhanced the ability to work in one team, even when personalities differ widely. * Students accomplished their goals by applying prior knowledge to solve the problem and finish the product.

6.6.3 Categories and themes

The qualitative data and the researcher's notes (observers' notes) was coded by means of Atlas.ti™. During the coding process attribute, descriptive, simultaneous and structural coding were applied which led to the identification of 298 secondary codes (see Figure 6.10 and Table 6.8) which could then be condensed into 59 primary codes and five themes.

Figure 6:9: Word cloud with secondary codes

Source: Compiled by researcher with the use of Atlas.ti™

One of the abilities of the Atlas.ti™ program is to compile a word cloud by using 'often-used words' while identifying different themes. The word cloud is shown in Figure 6.9.

The codes were refined into 30 categories and linked to five themes as emerged from the qualitative data (see Table 6.8). The themes are:

- Mechanical Technology (MT)
- Problem-Based Learning (PBL)
- Self-Directed Learning (SDL)

- Teamwork (TW)
- Reflection (R)

Table 6:8: Categories and themes identified from the qualitative research

Categories	Themes
Project development	Mechanical Technology (MT)
New skills	
New knowledge	
Prior knowledge	
Project work	
End product	
Complicated	
More thinking	
Assessment	
Share ideas	Problem-Based Learning (PBL)
Planning	
Brainstorming	
Learning objectives	
Communication	
Individual learning	
Solve problem	
Mature self-concept / confidence	Self-Directed learning (SDL)
Motivation	
Learning	
Interpersonal skills	
Self-discipline	
Commitment	
Higher-order thinking	
Planning	Teamwork (TW)
Management	
Organise	
Working together	
Project development	Reflection (R)
Progress	
Conflict	

Source: Compiled by researcher

6.6.4 Overview of qualitative findings

Note. As the majority of the participants were Afrikaans speaking the students' remarks and the researcher's remarks were translated to English to make them understandable.

All the qualitative findings were transcribed verbatim. With the use of concept and data driven coding, five main themes could be linked to the research results. Figure 6.10 shows an overview network view in Atlas.ti™ format of the themes and Figures 6.11 to 6.15 show individual networks for each theme. The figures show the relationships between certain categories within a certain theme.

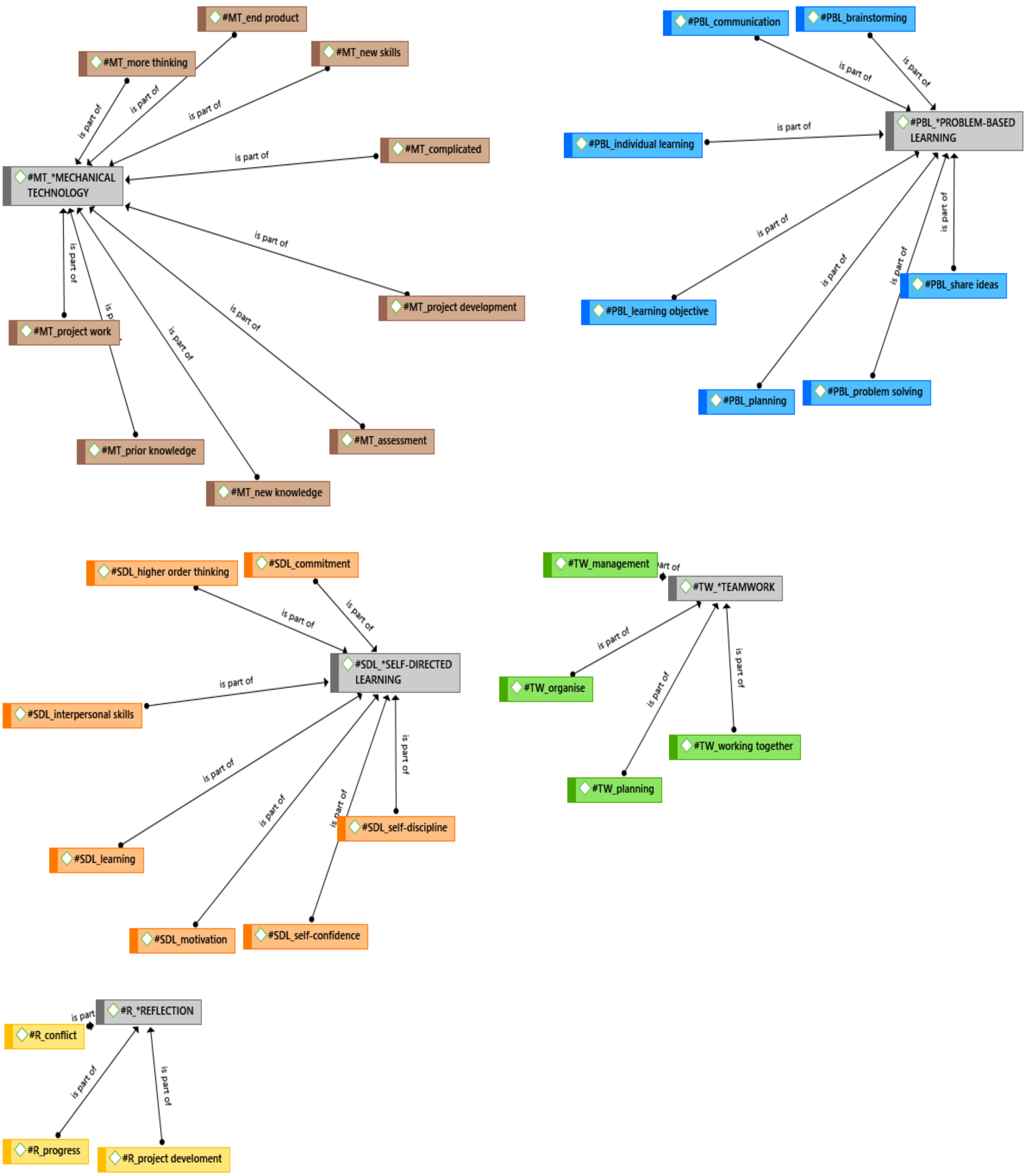


Figure 6:10: Network view of the five emerged themes

6.6.4.1 Theme 1: Mechanical Technology

In Figure 6.11, the themes and categories associated with Mechanical Technology are displayed.

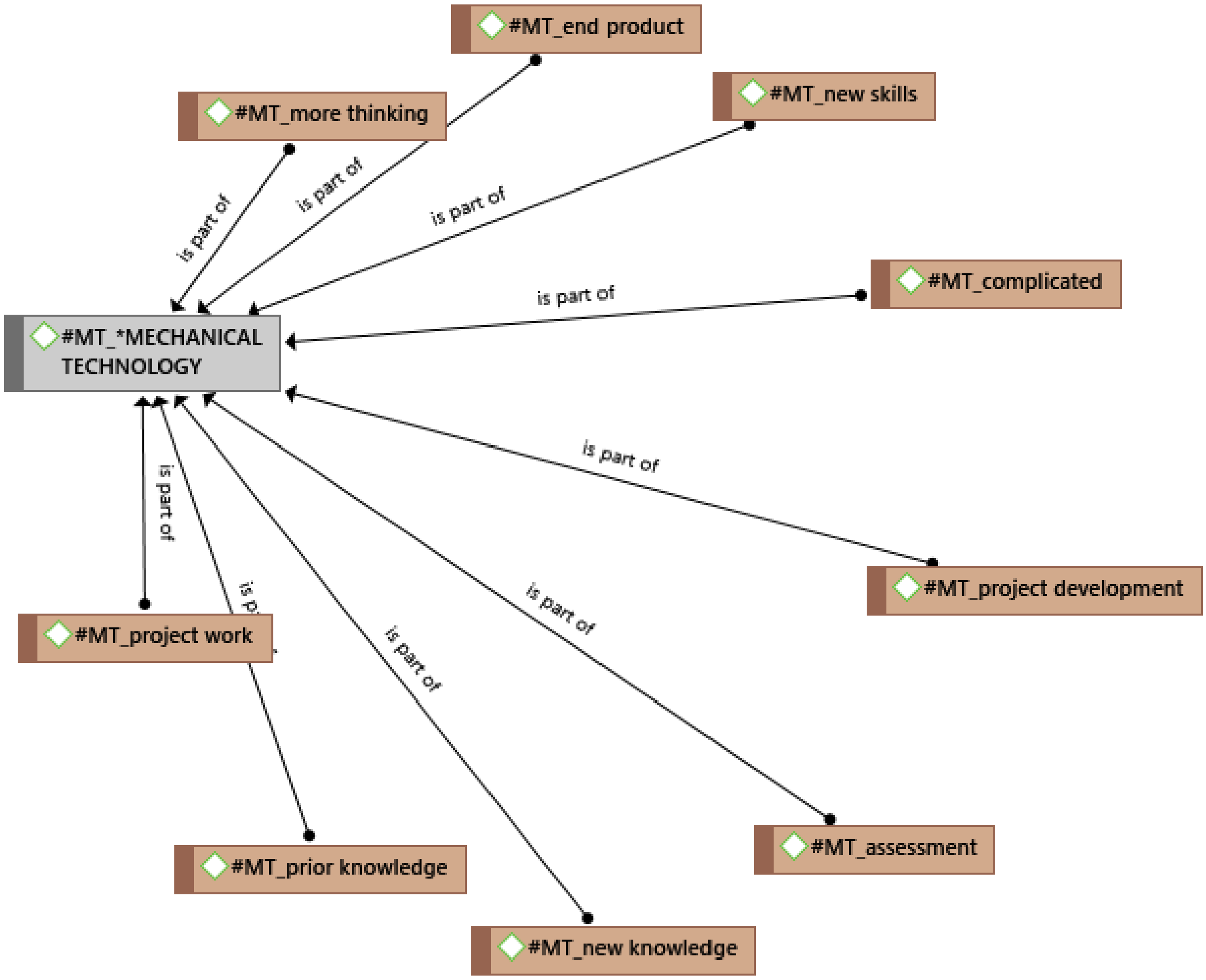


Figure 6:11: Mechanical Technology (MT)

In Table 6.9, the participants' comments regarding MT are displayed and thereafter the categories of each theme are discussed.

Table 6:9: Theme (MT) Mechanical Technology

Categories	Participants' comments
Complicated	A1 "Nie so maklik as wat dit gelyk het nie. Dit is moeiliker as wat ons verwag het." *[Not as easy as it looked. It is more complicated than we expected].* B9 "Al beplan jy. Dan besef jy wat jy op papier gedoen het werk nie so goed nie." *[Even if you plan. Then you realize what you've done on paper, doesn't work so well].*
New skills	B4 "Noudat ek kon sien en self doen verstaan ek beter.*" [Now that I could see and do it myself, I understand better].* B8 "…leer wat jy nie geweet het nie.*" [Learn what I did not know].* A7 "Ek verstaan nou beter." *[I understand better now].* A7 "Want dit is 'n leerproses." *[Because it's a learning process].*
New knowledge	B9 "Dan kom jy agter wat jy op papier gedoen het werk nie so goed nie." *[Then you realize what you've done on paper, does not work so well]. B8 "…* as jy werk en begin bou dan kry jy ander idees*" […when you work and start building, you get other ideas].*
End product	A9 "Ons het nog nooit so iets gedoen nie." *[We have never done something like this].* A5 "Die werk moet klaarkry." *[The work must get done].* A11 "As ons klaar is sal dit lekker wees om te sien wat die nut van die produk is." *[When done it will be nice to see the utility of it].*
More thinking	A7 "Ons moes leer om dit te kan doen, soldeer en sulke goed." [*We had to learn to do such things, solder and such].* B6 "Ons het lank gesukkel om die idee toe te pas." *[We struggled for a long time with how to put the idea together].* A7 "Daar is meer dinkwerk nodig." *[There are more thinking needed]*. B8 "… soos jy werk en begin bou kry jy ander idees wat beter werk, al het jy beplan." *[…as you work and start building, you get other ideas that work better, even if you planned].* B2 "Ja om eerlik te wees, ek het baie geleer uit die projekte, ek weet selfs waar my grense is en ek het meer selfvertroue om op te tree." *[Yes, to be honest I learned a lot from the projects. I even know my limits and I have more confidence to act].*
Prior knowledge	A3 "Die vaardighede wat nodig is, is amper dieselfde as by die vorige een." *[The skills necessary are almost the same as the previous one]*. B4 "Ons moes bietjie dink oor die ding en dan maar probeer." *[We had to think a bit about the stuff and then try it].* B4 "…vorige werk is belangrik. Ons leer van die ander projekte." *[…previous work is important. We learned from the other projects].*
Project development	B10 "Ons moes mekaar help met die kennis en die fisiese goed wat ons moes doen. Leer om die toetser te gebruik." *[We had to help each other with know how and the physical stuff we had to do. Learn how to use the tester].*
Project work	B12 "Ja dit is 'n goeie metode om te werk. Ek het geleer om te beplan, dink en bou. Daar is ander wat op jou staat maak." *[Yes I think it is a good way of working. I learned how to plan, think, and build. There are others to depend on].* B6 "Leer wat ons nie geweet het nie. En kan dit nou doen." [*Learning what we did not know. We can do it now].*
Assessment	B2 "Ons kon mekaar raad gee, en bespreek hoe om die problem anders aan te spreek" *[We could give each other advice, and discuss how to address the problem in a different way]*

Mechanical Technology. In Fig 6.11 MT is associated with categories complicated, more thinking, project work and development, end product, new skills, new knowledge, prior knowledge and assessment. (indicated by **"is part of"**).

- The phrases **complicated** and others were the actual categories that emerged from the data. Participating students reported that MT project development could be complicated as projects 1 to 4 were mainly 'ill-defined' problems, which challenged them. It encouraged them to develop new knowledge, build on prior knowledge and allowed them to develop new skills to solve new problems at hand. See examples of comments in Table 6.9 regarding the MT projects 1 to 4.

- Regarding the codes "**more thinking**", participants mentioned that they needed to get new ideas ('learn how to do, put ideas together' 'get other ideas that may work better'); since they did not understand, however, after 'more thinking' they understood. They did tests to find a way to fix problems and they experienced that if they put their heads together for 'more thinking' they enjoyed doing it and solved the problem faster.

- Regarding "**project work**", "**project development**" and "**end product**" as being part of MT, participants commented that they learned a lot from the 'project work', gained self-confidence, even found out where their limits of thinking and doing were and that they would know what to do with regard to project work in the future. Participants also said that the project work helped them to clarify the way forward and they were satisfied with the project results.

- The identification of **'new skills'** and '**new knowledge'** as a category also emerged as a result from comments made by participants that they had never experienced something similar before and that the tasks were tricky and challenging ('what you have done on paper does not work so well in practice').

- **'Prior knowledge'** is part of MT and also emerged from the data. Participants said they need prior knowledge to address new challenges. They mentioned that the second project was different from the first, implying that knowledge and skills gained from the first project were important in project work that followed.

- **Assessment.** Students had the opportunity to 'assess' their own work and those of peers in order to improve their projects.

As a result, the project development in the interventions helped students to obtain new skills, acquire new knowledge, use prior knowledge and made them think. Participants said that it was more complicated than what they initially expected. Although it is complicated or difficult, it is still essential and you need to learn things that you did not know before.

6.6.4.2 Theme 2: Problem-based learning

In Figure 6.12 the themes and categories associated with problem-based learning are displayed, in Table 6.10, the participants' comments are displayed and thereafter the findings are discussed.

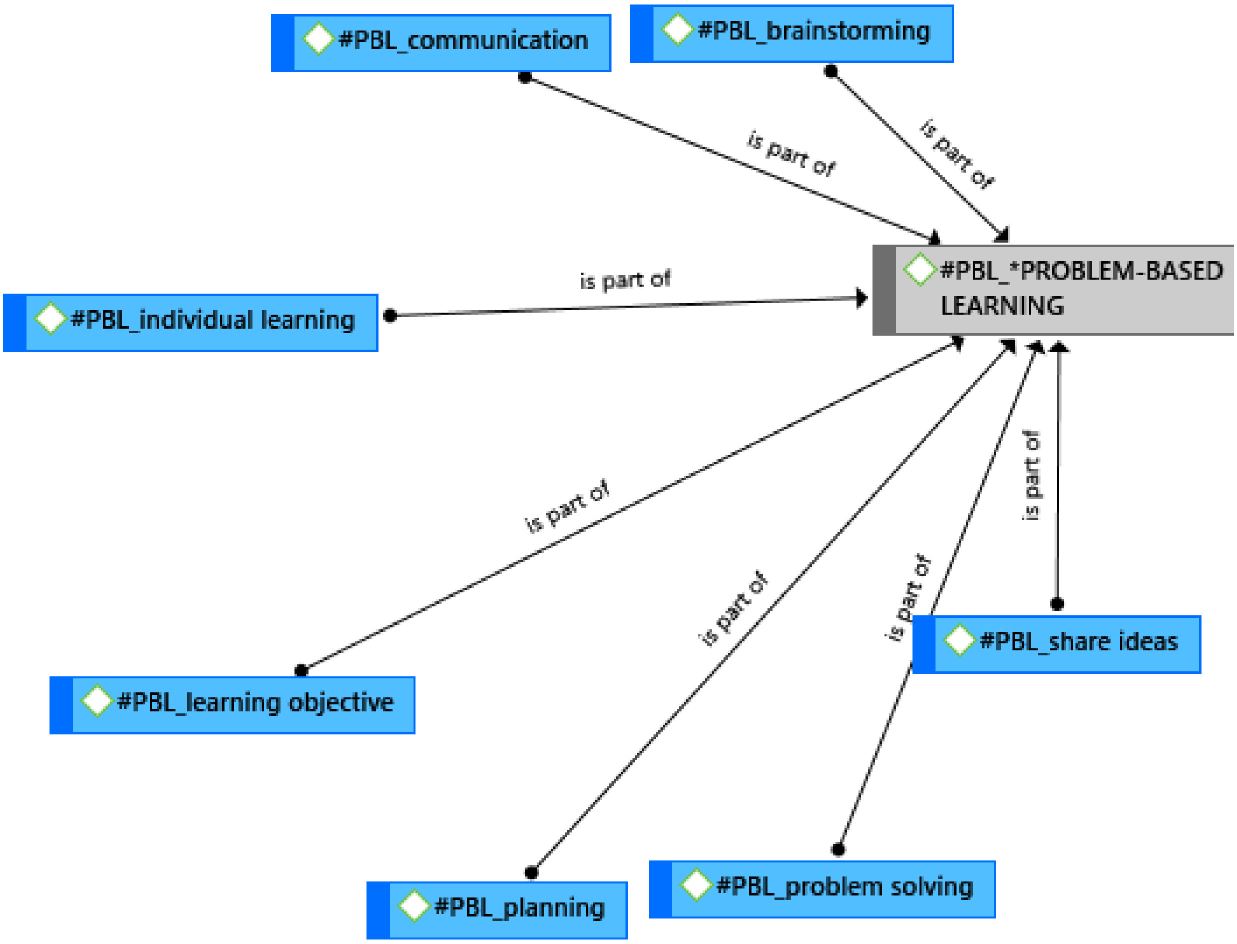


Figure 6:12: Problem-Based Learning (PBL)

Table 6:10: Theme Problem-Based Learning (PBL)

Category	Participants' comments
Brainstorming	A11 "Ons praat die hele tyd oor hoe ons die ding wil doen en dan sit ons dit aanmekaar." *[We talk all the time about how we want to do this thing and then we put it together].* A9 "...vir 'n lang ruk gesukkel hoe om 'n idee bymekaar te sit." *[…struggled for a long time to put an idea together].* A3 "Jy moet vir hom wys dit werk en dit vir hom verduidelik." *[You have to show him how it works and explain to him].* B4 "Soms sal hy jou 'n beter idee gee." *[Sometimes he will give you a better idea].*
Communication	B10 "Ons het lekker gekommunikeer." *[We communicated well]. A5* "Ons praat met mekaar en sorteer dit uit." *[We talk to each other and sort it out].*
Share ideas	A3 "Ons het idees gedeel." *[We shared ideas].* A5 "Ons het mekaar nodig." *[We need each other].* A1 "Ja, jy hoor die opinies van ander." *[Yes, you hear the opinions of others].*
Individual learning	B10 "As ek nie die kennis het nie kan ek by hom leer". *[When I lack knowledge I can learn from him].* A11 "Ons het beter nagevors die keer." *[We did better research this time].* A1 "…kom met 'n idee vorendag, so hy help waar hy kan." *[…came up with an idea, so he helps where he can].*
Learning objectives	B10 "…ons sien uit na die eindproduk." *[We are looking forward to the end product].* A9 "Ek het gehou van die end produk, die klaar produk het goed gelyk." *[I liked the end product, the finished project looked good].*
Problem solving	A7 "As jy werk en begin bou, dan kry jy ander idees wat beter werk." [*As you work and start building, you get other ideas that work better*]. B4 "Leer wat ek nie geweet het nie. Ek verstaan nou beter." *[Learning what I did not know. I understand better now].* A3 "…dit is net 'n leerproses, my gedagtes het verbreed." *[... it's just a learning process, my mind has widened].*
Planning	B10 "...gebruik die papier beplanning om die bord te beplan." *[…use the paper diagram to plan the board]*. A5 "…voltooi die beplanning." [...complete the planning]. A3 "… ons het vir die beste oplossing gesoek… ek kan nou probleme beter hanteer." *[...we looked for the best solution…I can cope better with problems now].*

Fig 6.12 displays the theme Problem-Based Learning (PBL) which was linked to different categories regarding PBL, namely; **brainstorming, communication, individual learning, learning objectives, planning, problem-solving, and share ideas.**

- **Brainstorming,** an important step in PBL was outlined as follows: A participant commented that he and his team mate constantly talked in order to formulate and implement an idea, another participant agreed and added that it sometimes takes time to brainstorm effectively. Brainstorming involves helping each other to understand. Most participants supported these views and elaborated on the idea that brainstorming resulted in new ideas, therefore initiating higher-order thinking.
- Regarding **communication**, students mentioned: "we communicated well, shared ideas, needed each other, apologise, and we go on". This strongly emphasises the

importance of communication and the exchange of ideas is an essential skill in PBL. Particular in group work where members need to take responsibilities and trust each other.

- Regarding **individual learning,** most participants commented in support of the findings to *take ownership of learning*, *metacognitive thinking, focus on a problem and goal setting*. The above supports the role of higher-order thinking that is needed for PBL. For instance, one participant replied that he learned a lot as individual and that he understood the need for setting learning objectives. Other participants did not directly mention the necessity of setting learning goals, however they emphasised the importance of individual learning. Others mentioned that they *got more knowledge* by applying PBL in MT.

- **Sharing of ideas** was commented on as follows: “My team mate helped me a lot”, “My partner is for example good with planning and I am good with the physical work”, “we had to share our ideas”. “You can't rely on one guy alone”.” Yes one has an idea and one of the other also has an idea and we both were too stubborn to leave the idea” and another team mate served the role of mediator. The comments regarding sharing ideas indicate that students did indeed share ideas, relied on each other, needed and assisted each other during the project develoment.

- Regarding **problem-solving**, participants made comments such as; “You should select simple designs to solve problems and plan on paper before development starts”. This was confirmed by members who also stressed the importance of complete planning while another said he can cope better with problems as a result of the interventions and emphasised the importance of planning. The findings strongly correspond with the literature review. In section 2.3.4 the importance of addressing problems, finding feasible solutions to problems, engaging with the problem and project planning are discussed. The comments thus give an indication of the role that self-directed learning played in the interventions.

- **Learning objectives.** Participants commented that their projects demanded much more detailed planning and work than they initially anticipated, by highlighting the importance of setting learning objectives and the need for higher-order thinking. In addition, formulating objectives is an essential PBL step (see Table 2.2).

- **Planning**. The importance of planning was confirmed by many participants who made comments such as: “We had to think hard and try even harder”; “We watched videos about these things”; “We made many sketches”; ‘We often changed our idea”; “We got basic design ideas from the internet and adopted it” and “We had to make our own sketches to clear our vision”. The literature review reinforces the opinion of students that planning is a very important step for PBL, SDL and the development of higher-order thinking.

As discussed in chapter 2, problem-based learning relies on constructivist principles and involves, among others, steps such as group work, identification of the problem, brainstorming, individual study, good communication, conflict resolution, experiments, literature reviews, evaluation and sharing (see Figure 2.3 and 2.4). The themes identified by means of Atlas.ti™ correspond and align with the characteristics of PBL and the implementation thereof.

6.6.4.3 Theme 3: Self-Directed Learning

The theme Self-Directed Learning (SDL) was associated with the following categories, namely **interpersonal skills**, **commitment**, **higher-order thinking**, **motivation**, **self-discipline**, **learning** and **self-confidence** (see Figure 6.13 and Table 6.11).

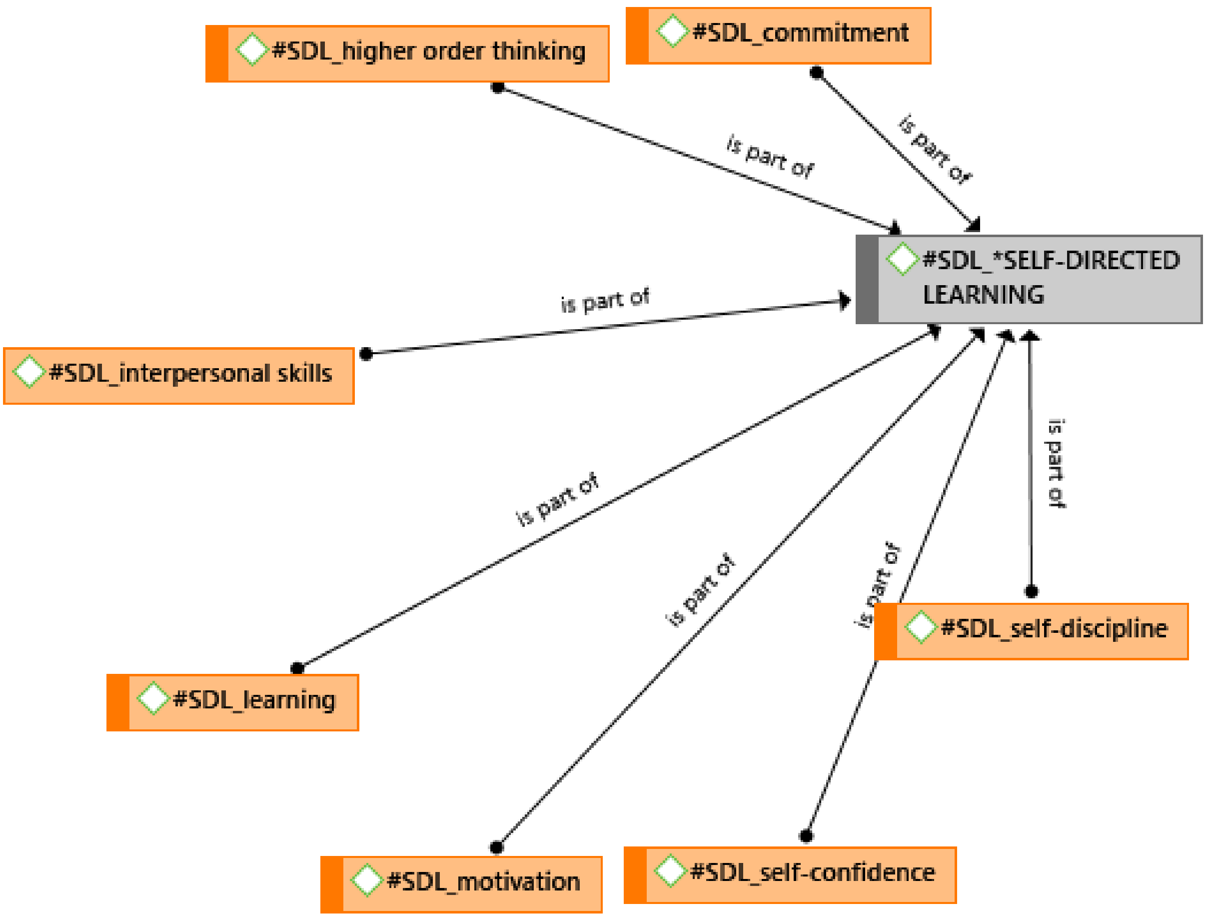


Figure 6:13: Theme Self-Directed Learning

In Table 6.11, the participants' comments regarding SDL are displayed and thereafter the categories of each theme are discussed.

Table 6:11: Theme Self-Directed Learning

Categories	Participants' comments
Commitment	A11 "Ons het as 'n span gewerk." *[We worked as a team].* A3 "Ons het die verantwoordelikhede 50/50 gedeel." *[We shared the responsibilities 50/50].* B8 "Ons hou daarvan en maak goeie vordering." *[We like it and are making progress].* B2 "Ons het goed in spanverband gewerk om die kar klaar te maak." *[We worked well in a team in order to complete the car].* A3 "Ons het mekaar gehelp soos nodig" *[We helped each other as needed].* B8 "Maak die projek betyds klaar." *[Complete the project on time].*
Self-discipline	A1 "Ja, ek voel nou 'tuis' soos ek leer om my tyd te organiseer en meer te verdeel." *[Yes, I feel at home now as I learn how to organise my time and divide the work].* B8 "Maak seker ek het al die komponente wat ek benodig." *[Make sure I had all the components that I needed].* A3 "Wel ek het nie veel bystand benodig nie…" *[Well I did not require much assistance…].* B10 "Ek hou van die kreatiwiteit wat benodig word, my kop het oopgegaan..." *[I like the creativity that is needed, my mind has widened...].* A5 "Ons het stadig begin, maar later vinniger begin werk." *[We started slowly, but later we worked faster].*
Self confidence	B2 "Die feit dat ons dit kon regkry." *[The fact that we could get it right].* A5 "Maar ons het die uitdagings opgelos." *[But we solved all the challenges].* A5 "Jy het jou spanmaat, maar hy maak ook op jou staat." *[You have your team mate to help you, but he also relies on you].* A9 "Die 'selfdoen' deel…" *[The 'self do' part…].* B12 "As jy eers begin, word dit meer duidelik wat om te doen." *[Once you begin, it becomes more clear what to do].*
Motivation	A3 "Ons het ons 'ge*commit*', ons moes dit klaarmaak." *[We committed ourselves, we had to finish it].* A9 "Ons was 'n span, ons het deurgedruk." *[We were a team, we pushed through]. B6* "Ja, ons moes die verantwoordelikhede aanvaar en deel." *[Yes, we had to accept the responsibilities and share it].*
Learning	A1 "Ons het geleer om mekaar te aanvaar." *[We learned to accept each other].* B4 "As ons sien iemand sukkel, dan kyk ons of ons kan help." *[If we see someone struggling, we see if we can help].* B8 "Kyk na verskillende oplossings." *[Look at different solutions].* A7 "Ja, ek voel meer ek het baie nuwe dinge geleer." *[Yes, I feel more I have learned many new things].* A7 "Maar al het jy kennis is dit beter as jy 'n spanmaat het, want twee is beter as een." *[But even if you have knowledge, it is better if you have a partner, because two is better than one].*
Interpersonal skills	A7 "Ons het lekker saamgewerk." *[We enjoyed working together]*. B4 "Ons moes leer om mekaar te aanvaar en ons verskille uitsorteer." *[We had to accept each other and sort out our differences].* A11 "Ons was hoflik met mekaar al was ons nie van dieselfde geslag nie." *[We were polite with each other even though we are not from the same gender].*
Higher order thinking	A11 "Die uitwerk van die stuurwiel was die moeilikste deel, maar 'n lekker uitdaging." *[To figure out the steering system was the most difficult part, but a nice challenge].* B12 "Ons moes bietjie dink en weer teruggaan na ontwerp." [*We had to think a bit and go back to the design].* P8 "Dit leer ons om eers te dink voor jy begin werk." *[It teaches us to think before you start working].* A11 "Dit is 'n moeilike en uitdagende projek." *[It is a difficult and challenging project].*

Self-Directed Learning themes (see Table 6.11 and Fig 6.13) were linked to **commitment, self-confidence and self-discipline, motivation, learning, interpersonal skills and higher-order thinking.**

- **Commitment**. During the two interventions it emerged from the data that students really committed themselves. The participants implied their commitment by equally sharing responsibilities, by making sure they complete their task on time, by giving cooperation in teams and by assisting each other. This corresponds with the description of Mowday *et al*. (2013) as the act of binding yourself to a course of action.

- With regard to the theme **self-discipline**, respondents mentioned that one must first look carefully at how it works before you start working, that the intervention guided them to think first before they start working. To ensure they had every component they were going to use and one student said he had to design and work out an appropriate length to shape the vehicle. These are all terms associated with self-discipline.

- During the interventions, participants worked with **self-confidence.** Participants remarked that they succeeded in solving the challenges, they had confidence to help other members of the team and that they depended on each other. These characteristics, as mentioned in the literature (see Section 1.4.1), are essential for SDL as they allow students to develop a plan for completing the work, be responsible and to enjoy their work at the same time.

- Participants did enhance their **motivation** with the challenges they were presented with. Participants were motivated to commit themselves, to finish what they have started, they pushed through and accepted responsibility for all team activities. Evidence thereof can be found in Table 6.11 and from the literature review, it was established that the motivational features of PBL more than often outweighs the negative features thereof.

- Both interventions provided various opportunities for **learning**. As the projects were ill-structured, students were required to find resources, learn from each other, use prior knowledge and seek assistance in more than one way.

- **Interpersonal skills.** Participants commented in this regard with phrases such as "we enjoyed working together", "we had to accept each other and sort out our differences" and we were "polite with each other*…".* As discussed in chapter 2 (see 2.3), in teamwork and cooperative learning, interpersonal skills are important ingredients regarding PBL, SDL and to some extent to higher-order thinking as it allows the members of the team to, among others, break complex tasks into smaller bits, foster time management, improve understanding through discussion, provide feedback on performance, and improve communication.

- Evidence of **higher-order thinking** was found in the transcribed qualitative data. Participants mentioned the challenging nature of the projects, the level of difficulty and that they even underestimated the extent of the tasks. Some of the more challenging aspects were the design and development of the steering systems, the wiring for the relays, solenoids and some other (hidden) circuits. Some even stated that it was difficult, complex and that they had to think a lot and sometimes had to rethink their designs. In the literature, it was found PBL is important as it includes various teaching and learning elements such as planning, interaction, and reflection that could enhance higher order-thinking, problem solving and self-directed learning.

The evidence found in the literature coincides with the qualitative data to enhance SDL and other accompanying abilities such as motivation, self-confidence, higher-order thinking and commitment by means of both PBL interventions. These are all ‘skills’ that participants needed and developed during the interventions. This was confirmed by the literature review (see Table 3.1). Participants also experienced high levels of self-confidence, self-discipline and ‘learned’ a lot during the completion of the four projects. This was particularly indicated by the following quotations ‘we shared the responsibilities 50/50’; ‘helped each other’; ‘made sure that I had all the components I needed’; ‘self-do part’; ‘we committed ourselves, we had to finish’.

6.6.4.4 Theme 4: Teamwork (TW)

In Fig. 6.14, the responses of participants regarding the theme Teamwork are displayed. The categories associated with teamwork are **planning, working together, management** and **organise.** Some of the comments students made during group meeting sessions are listed in Table 6.12.

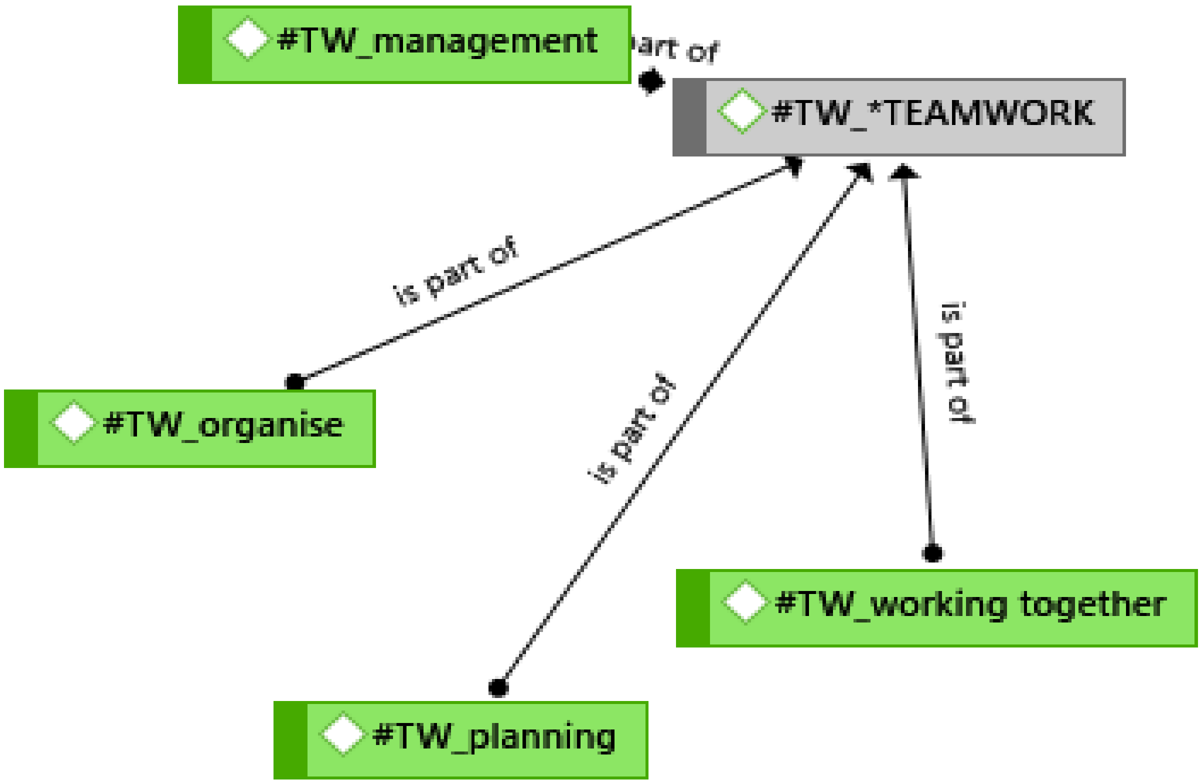


Figure 6:14: Theme Teamwork

Table 6:12: Theme (TW) Teamwork

Categories	Participants' comments
Planning	B6 "Ek sou beter tydbeplanning gedoen het.'' *[I would have done better time planning].* A11 "Ek moes meer inligting gekry het." *[I should have looked for more information]*. B2 "Ek het die beplanning gebruik om die gegalfiniseerde stroombaan te maak en om 'n werklike stroombaan te bou." *[I used the planning to make the galvanised circuit in order to complete a real circuit].* A5 "..die beplanning van die bord voor die tyd het baie gehelp." *[…the planning of the board at first really helped].* B12 "…ek het 'n voorlopige ontwerpplan gebruik." *[…I used a drawn/planning diagram].*
Working together	B2 "… ek het geleer dat ek en my spanmaat saam die wa moet trek. Ons moes self die verantwoordelikheid neem." *[… I learned that my teammate and I should pull together. We had to take the responsibility ourselves].* A5 "… want twee koppe is beter as een." *[… because two heads together is better than one].* B6 "Ons het beide ingestem dat ons saam verantwoordelik was." *[We both agreed that we are responsible together].*

Management	B12 "Ons het lekker gekommunikeer." *[We communicated well].* A5 "Ons het idees uitgeruil." *[We shared ideas]*. A11 "Ons het konstant gepraat oor hoe om die ding te doen en dit bymekaar te sit." *[We talk constantly about how we want to do this thing and put it together].* A1 "Dit is soos 'n navigator en bestuurder." *[As with a navigator and driver].* B4 Ons sal dit professioneel hanteer en leer hoe om te beplan, dink en bou." *[We will handle it professionally and learn how to plan, think, and build].* A9 "Ja jy hoor ander se opinie." *[Yes you hear the opinions of others].*
Organise	A9 "Jou beplanning moet korrek wees, voor jy enige iets kan doen." *[Your planning must be correct before you can do anything].* A9 "As ons nie saamstem oor iets nie, dan redeneer ons die probleem uit tot dit reg is." *[If we disagree on something, we reason until we have it right].* A11 "Ek het die helfte van die beplanning gedoen en vir A9 rondgestuur." *[I did half of the planning while sending A9 around].* A5 "Ons het die verantwoordelikhede altyd gedeel, dit was makliker vir ons 3." *[We always shared the responsibilities, it was easier for the three of us].*

Teamwork. In Table 6.12, the responses of participants with regard to the theme teamwork (TW) were associated with the words **planning, working together, management** and **organise**.

- **Planning** involves many facets and action steps. During the group meetings and interviews, participants elaborated on this by mentioning that they had to break complex tasks into smaller bits, use time management, discuss issues to improve understanding and learn how to delegate. Knowles (2007), a pioneer with regard to SDL, mentions that self-direction is a learning process in which the student undertakes self-planned learning by taking control of the process.

- **Working together.** This implies the use of small groups to foster ''cooperativity, knowledge, routines, skills, competences, and abilities needed for teamwork". The participants commented by stating that they learned that teammates should pull together, take and share responsibilities. Their comments actually refer to most of the teamwork features identified in chapter 2 such as cooperation, working together, shared responsibilities and common objectives.

- The term **Management** is usually associated with **planning** and **organising**. During the interviews and group meeting sessions, remarks were made in this regard. These remarks refer to communication, talking, how to put things together, professional handling of problems, planning, thinking, building, opinions of others, agreement and resposibilities. These management actions relate to time management, feedback, improvement of communication, skills development, collaborative learning and teamwork as found in the literature.

To summarise, the features, aims and objectives of teamwork, group work and PBL are related with the abovementioned responses. As discussed in chapter 2, the role of teamwork is also important when applying PBL, as it closely resembles real-world settings where students need to share responsibility and liability with regard to the problem (Michaelsen *et al.*, 2014). The Aalborg model is also characterised by the use of teamwork that relies on constructivist principles and involves, among others, steps such as group work, identification of the problem, brainstorming, individual study, good communication, conflict resolution, experiments, literature reviews, evaluation and sharing (see Table 2.4 and Figure 2.3 and 2.4). Participants' feedback corresponds and aligns strongly with the characteristics of teamwork and the implementation thereof. Examples of students' comments in support of these are shown in Figure 6.14 and students' arguments are shown in Table 6.12.

6.6.4.5 Theme 5: Reflection (R)

In Fig. 6.15, the responses of participants regarding the theme Reflection are displayed. The categories associated with reflection are **conflict, progress** and **project development.** Some of the comments participants made during group meeting sessions and interviews are listed in Table 6.13.

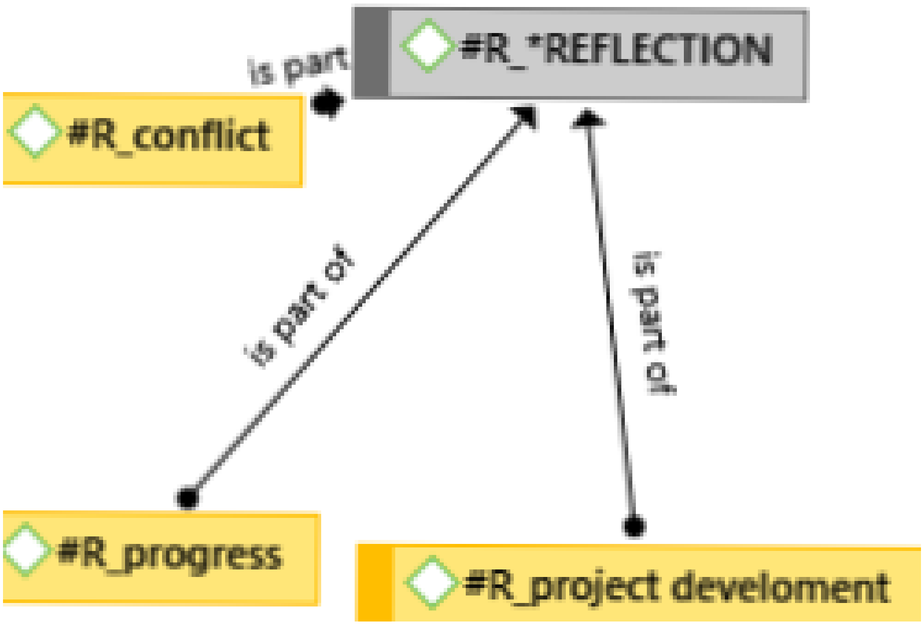


Figure 6:15: Theme Reflection

Table 6:13: Theme (R) Reflection

Categories	Participants' comments
Conflict	A11 "Nee, wel verskille, maar nie konflik nie." *[No, we did have differences, but no conflict].* B8 "Ons sal nie stry met mekaar nie…redeneer...vir 'n nuwe plan." *[We will not argue….reason…for a new plan].* A1 "Ons menseverhoudinge word ook getoets" *[Our human relations are tested as well].* B12 "Klein haakplekkies hier en daar…wat ons gou opgelos het." *[Small hiccups here and there…small incidents which we quickly resolved].* B6 "Ja 'n bietjie, die dame was bietjie dominant." *[Yes, only a bit. The female was a bit dominant].*
Progress	A1 "Ons het van tyd tot tyd gesukkel, maar ons het dit hanteer." *[We struggled from time to time, but we managed].* B6 "Saamtrek maak dat individuele werk nie so moeilik is nie." *[Working together makes individual work less difficult].* A2 "Ons het die werklas verdeel." *[We divided the work load].* A11 "…ek het steeds soms onbevoeg gevoel." *[I still felt a little incompetent sometimes].* B2 "Ons het meeste probleme opgelos." *[We resolved most problems].* B2 "…nie te vinnig en nie te stadig." *[…not too fast and not too slow].*
Project development	B12 "As jy eers begin, kry jy nuwe idees wat beter kan werk al het jy beplan." *[As you start, you get other ideas that work better even if you did plan].* B4 "So ons kry meer kennis hierdeur." *[So we also got more knowledge by doing this].* B6 "Leer wat ons nie geweet het nie." *[Learning what we did not know].* A2 "ons het nog nooit so iets gedoen nie. Ons het geleer om saam te werk en om kreatief te wees." *[We never did something like this. We learned to work together and to be creative].* B10 "Ons het mekaar meer bevoeg gemaak." *[We made each other more competent].*

- **Reflection,** is an important aspect of SDL (see Section 3.2.2) and PBL (see Sections 2.3.3 and 2.6) in that it allows students to 'look back' and reflect on their own work and those of the people who worked with them (team members).

- **Conflict.** The management of conflict and conflict resolution are important skills in teamwork and PBL. Participants did mention that they had conflict during the PBL process and also how they handled it. Although the conflict that developed during the interventions were minor, participants skilfully managed and resolved it by means of effective communication, mediation and professional conduct. As a result the opportunities to reflect on the projects did enhance the ability of students to manage conflict and therefore contribute to becoming more self-directed as students learn from one another.

- **Progress** refers to the development of particular skills or the completion of tasks over time. During the development of the four projects, participants had ample time to plan and steer their activities in order to make good progress. Participants indicated ‘we struggled from time to time, but we managed. They achieved this by dividing tasks, careful planning, sticking to their time schedules and by helping each other. Although all teams completed their projects in the allocated time it would have been better if there were more time available.

- **Project development** is part of the PBL process and in this study, the seven steps described in Section 2.4.3 were used for the development of the four artefacts. Participants mentioned, in their conversations during the meetings and interviews, that they got ideas that work better while working on artefacts and projects, they obtained more knowledge and they made each other more competent.

The responses in Fig. 6.15 concur with the findings in the literature, as participants made comments in support of the importance of reflection as part of the PBL process. For instance, Boud *et al.* (2013) found reflection in PBL useful, since it helps to monitor and consolidate the learning that developed during the PBL and it serves as reinforcement for refining metacognitive thinking. Further, reflection fosters self-thinking, critical thinking and active learning. These skills are essential in the development of SDL. Reflection (self- and group reflection) supported students to enhance their SDL, as it improved understanding, challenged their assumptions, highlighted the roles of accountability and responsibility and assisted them in finding new ways to solve problems.

6.7 Discussion of results

In this study, both quantitative and qualitative data were gathered and analysed. Only descriptive statistics was used as the population of students enrolled in the VTEE course in the second and third year was small. The quantitative results indicated that the mean SDL values slightly decreased from the pre-test (2017) to the post-test in 2018 (235.19 to 226.47). Furthermore, changes were noticed during both interventions in students' individual scores. A decrease in the constructs (awareness, learning strategies, learning activities, evaluation and interpersonal skills) was noted in some students' results, few had similar scores whereas others indicated an increase in one or more SDL constructs. Changes in individual SDL total scores for 2017 and 2018 were displayed in Figure 6.7

and 6.8. However, from these figures it is clear that most participants indicated high SDL scores (above 220) during 2017 and 2018. Although there is a discrepancy in results, the value of the four projects should not be overlooked, as some students indeed improve their self-directedness to some extent. Further, a decline in the values could be due to the fact that participants underestimated the work and responsibilities involved in the projects. The lecturer (researcher) reduced his involvement and assistance to participants during project 3 and 4 as they were supposed to take responsibility and ownership, do research, set clear objectives, design and develop the project on their own. Due to inconsistency in quantitative results, the researcher analysed qualitative data to get a clear indication regarding students' hPBL experiences during the two interventions as well as the possibility of enhancing their SDL.

From the qualitative data, five themes emerged, namely Mechanical Technology, Problem-based learning, Self-directed learning, Teamwork and Reflection. Various examples of participants enhancing their self-directed learning were obtained. Some examples of responsible SDL are outlined. Students did more thinking, developed new knowledge and skills when working on the projects:

> "…it is a good way of working. I learned how to plan, think and build" (B6) [MT Theme – Project work category];
> "… when you work and start building, you get other ideas"(B8) [MT Theme – New knowledge category];

Participants also planned, analysed their own learning needs, took initiative, formulated their learning goals, identified resources and implemented appropriate learning approaches during the interventions. Some examples thereof are the following:

- "When I lack knowledge I can learn from them" (B10) [PBL Theme – Share ideas category];
- "We did better research this time" (A11) [PBL Theme – Individual learning category];
- "…we looked for the best solution… I can cope better" (A3) [PBL Theme – Planning category];
- "We will handle it professionally and learn how to plan, think and build" (B4) [PBL Theme – Teamwork category].

For example, participants also mentioned their experiences regarding responsibility, curiosity, active learning, self-motivation and construction of knowledge, e.g.:

- “The work must get done” (A5) [MT theme – End product category];
- “We are looking forward to the end product” (B10) [PBL Theme – learning objectives category];
- “… we learned from the other projects” (B4) [MT Theme – Prior knowledge category];
- “Learning what we did not know”. We can do it now” (B6) [MT Theme – Project work category];
- “We commited ourselves” (A3) [SDL Theme – Motivation category];
- “Yes, we had to accept the responsibilities and share it” (B6) [SDL Theme – Motivation category].

The examples provided above are in line with the literature (see Sections 3.2.2 and Table 3.2) were it was found that important characteristics of SDL are amongst other: self-concept, adoptability regarding learning needs and strategies, addressing problems, planning and control of learning, self-informing, experimental learning, goal setting, value of own learning, enhancement of skills, application of knowledge curiosity and motivation. Interpersonal skills such as good communication, commitment to the project, development of higher-order thinking to solve intricate problems and the use of self-discipline were all ‘skills’ that participants needed and developed during the interventions.

Participants also experienced high levels of self-confidence, self-discipline and ‘learned’ a lot during the completion of the four projects. All these are traits of SDL and therefore one can associate the intervention with a process to enhance SDL. As a result of the hPBL interventions workshop challenges were addressed, students understood the hPBL process, they enjoyed the teamwork and worked towards a common goal. Evidence was also found that hPBL enhanced practical knowledge and skills as they ‘learned skills’ from one another and mentioned that they have ‘learned new’ and ‘more advanced’ skills. The acquisition of higher levels of knowledge and skills during the interventions are especially applicable when they moved from 2017 to 2018. Students indicated the importance of planning, research, group work, good interaction and communication skills, group cohesion and growth concerning interpersonal abilities, and this should in turn enhance their knowledge and skills.

6.8 Conclusion

From both quantitative and qualitative results, it is clear that most students enhanced their SDL to some extent. Ill-structured problems with various pathways to solve them were used in MTA practical classes where a scaffolding curriculum and reduced lecturer involvement were present. In this research the quantitative and qualitative data as well as the literature revealed that the application of hPBL in MTA practical sessions, to some extent, enhanced some pre-service teachers' self-directed learning, higher-order thinking and practical knowledge and skills. A summary of the findings are provided in Figure 6.16 below.

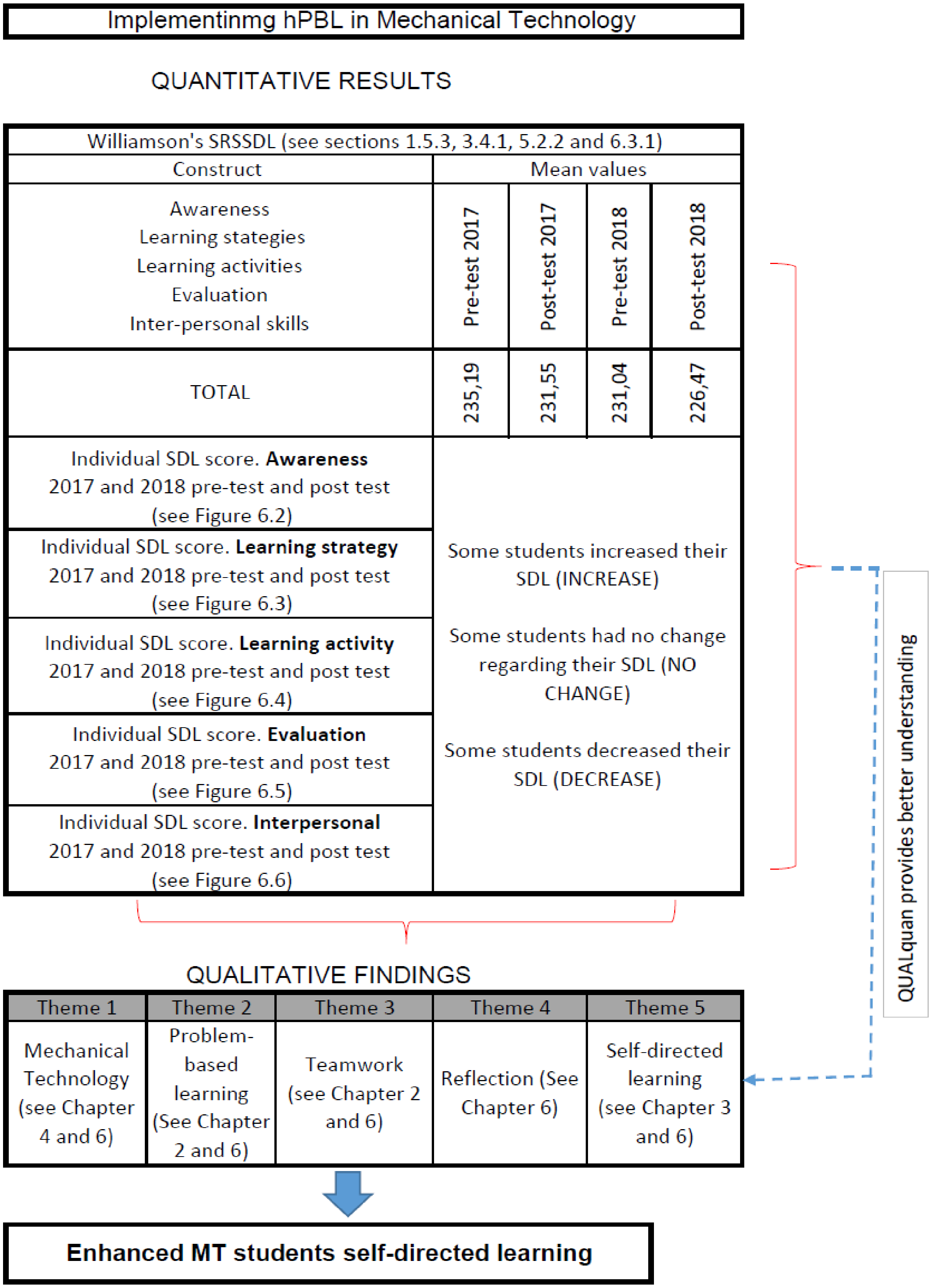


Figure 6:16: Integrated overview of research findings

CHAPTER 7: CONCLUSIONS AND RECOMMENDATIONS

7.1 Introduction

The previous chapters focused on the literature overview and empirical research. This chapter as based on the body of scholarship as well as conclusions from empirical work is focused on summarising each chapter, furthermore, the ultimate aim is to answer the research question and sub-questions as well as making recommendations as based on answering the research questions. Contributions of this study as well as some limitations are also addressed.

7.2 Chapter summary

Chapter one outlined the problem statement and provided a brief literature review regarding the background of this study. The rationale for the study, the research questions, the aims thereof, the clarification of relevant terminology as well as the empirical methods used in this study were outlined.

Chapter two provided a thorough theoretical overview and history of problem-based learning (PBL) as well as the theoretical perspectives in which PBL was founded. The use of PBL in education, as well as the advantages and effective assessment methods thereof were discussed. In particular, the focus was on hPBL as teaching-learning strategy for this study.

Chapter three consisted of a detailed outline regarding self-directed learning (SDL). Theoretical approaches in support of SDL, the rationale for enhancing SDL in classrooms, effective assessment thereof as well as the role and use of SDL in Mechanical Technology were discussed.

Chapter four provided a comprehensive review of the FET subject Mechanical Technology (MT). Regarding MT in South Africa, a brief history of 'technical' subjects were provided as well as the requirements for Mechanical Technology teacher education. The implementation of PBL in MT classes at university was also addressed.

Chapter five gave a complete description of the empirical research conducted. This included the research paradigm, methodology, design, aims, objectives, population, time schedules, data collection and analyses. The research instrument and methods were discussed in detail and all relevant values displayed. In addition, trustworthiness, ethical aspects, the design-based research process and project details were outlined. The implementation of the hPBL interventions was explained, project development was outlined, written and pictorial evidence thereof was provided and the organisation of students' participation was outlined.

Chapter six outlined the research results and findings. Data analyses of both quantitative and qualitative research were explained in full and diagrammatic evidence thereof was given. Details of all four projects, including pictorial evidence and student exemplars were included. This chapter also comprised qualitative and quantitative results (including Atlas .ti™ diagrams) as well as an integrated discussion and overview of the research findings.

Chapter seven, the closing chapter summarised the thesis and provided answers to the research questions. This chapter also provided an integrated framework, a model for implementing PBL in Mechanical Technology practical classes, study limitations, suggested further research as well as recommendations.

7.3 Discussion and findings

Qualitative and quantitative research were used to answer the questions as reported on in chapter 6. This chapter also reports on the concepts from the literature and empirical findings that indicated that it is possible to affect student learning in a favourable SDL direction if appropriate ill-defined PBL problems of interest are selected and integrated into the MTA curriculum.

7.4 Conclusions regarding question 1: What does Mechanical Technology, problem-based learning and self-directed learning entail?

In this section, conclusions are drawn from the body of scholarship, pertaining Mechanical Technology, problem-based learning and self-directed learning.

7.4.1 What does Mechanical Technology entail?

The literature review in Chapter four provided insight into what Mechanical Technology, as part of Technology education, entails. Several countries across the world initiated Technology Education to be offered at different institutions and educational sectors in developed and developing countries (see Section 4.4). In South Africa, formal Technology education was provided with the founding of some industrial schools (see Section 4.5). Thereafter, technical and vocational training gained momentum in many schools, colleges training and higher institutions. The subject Technology was introduced in 1997 to keep with international trends regarding Technical Education. However, due to some challenges curriculum documents were amended in 2010 to make provision for Technology in three school phases (Intermediate, Senior and FET). In 2014, a new technology curriculum, called CAPS (specialisation), was introduced in South Africa and included MT as one of the technology specialisation in the FET phase for Grades 10 to 12. MT provides embedded knowledge regarding specific Automotive, Welding and Metalwork, and Fitting and Machining content. These three school subjects serve the purpose to equip learners, with the knowledge, skills, and values necessary for self-fulfilment and meaningful participation in society as citizens of a free country.

MT, in general, focuses on, amongst others, safety, tools and equipment, materials, terminology, forces, maintenance, systems and control, gears, belts, pulleys, transmissions, levers, hydraulics, pneumatics, direct current (DC) electrics, engines, pumps, and turbines. In the Automotive component of Mechanical Technology (MTA), learners are educated and instructed in industry-related automotive matters. The topics covered in MTA are shown in Table 4.3. In addition, an integrated representation of MT is displayed in Figure 7.1.

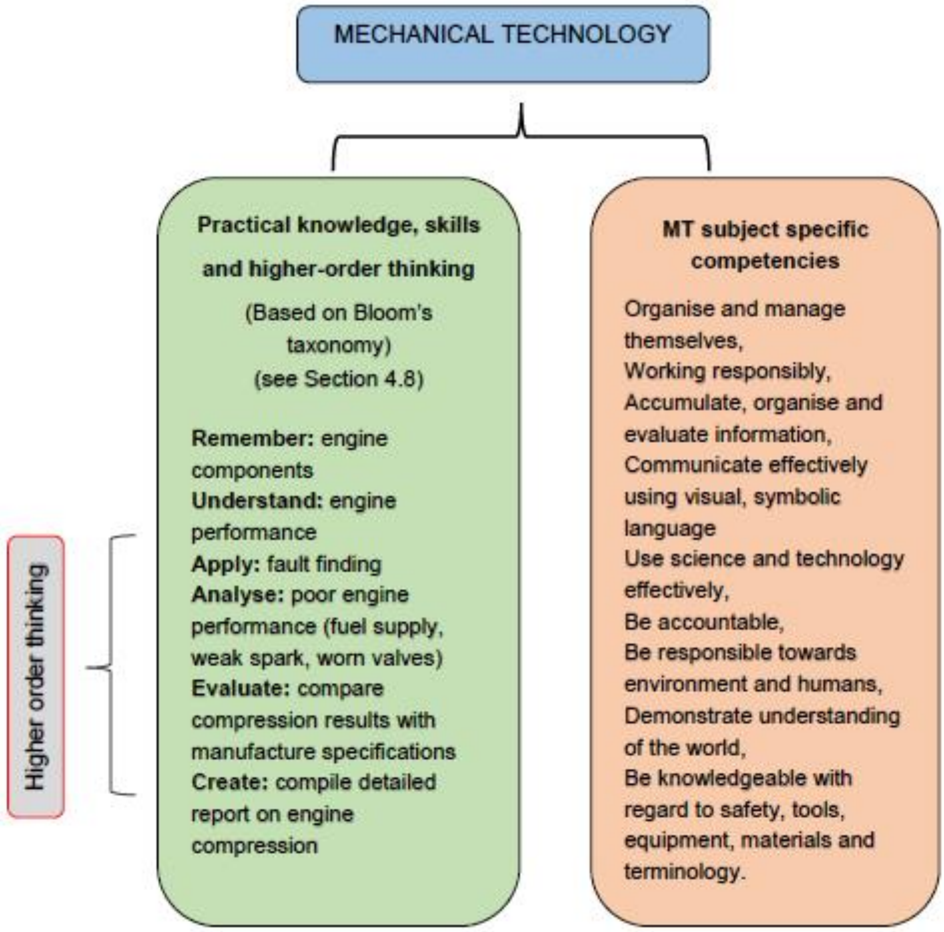


Figure 7:1: Integrated representation of what MT entails

The practical knowledge and skills and higher order thinking based on Bloom's taxonomy are displayed in Figure 7.1 and are discussed in Section 4.6.1.1 and the application thereof are discussed below.

In MT, the competencies include theoretical as well as practical knowledge and skills as needed in a workshop. The practical competencies needed in a MT workshop can be classified in three groups, (see Section 4.7) namely:

- General practical competencies for MTA and related subjects, such as welding, drilling, shaping, measuring and testing;
- Specific technology competencies for MTA, such as how to use a gas analyser, compression tester and a timing light;

- Specialised technology competencies, such as using a CNC milling machine and lathe, calculating clearances as well as the ability to apply mathematics, programming and operating skills.

MT is therefore a subject requiring various technical knowledge, skills and competencies, allowing students to use an MT workshop. This includes the use of knowledge, skills, tools and equipment with responsibility and safety and use higher order thinking to apply the knowledge and skills by analysing, evaluating and creating in a creative, innovative and responsible way.

7.4.2 What does Problem-Based Learning entail?

PBL probably originated from constructivism that describes learning as a result of a cognitive process (see Section 2.2.1). Social constructivists believe that learning is a process whereby reality and knowledge are constructed by social interaction through human activity. There are some similarities between constructivist thinking, PBL and social constructivism, since all emphasise that learning develops through interaction, the use of small groups and the reduction of lectures. It was found that institutions such as Maastricht and Aalborg, scholars and philosophies such as Dewey, Barrows and Marxism, played an important role in the development of PBL (see Figure 2.1).

According to Barrows and Tamblyn, (see Section 2.3) PBL is learning that originates from the practice of working toward the resolution of a problem. The problem is faced first in the learning process and then serves as a focus for the application of problem-solving skills, as well as for the search for information or knowledge needed to understand the problem and how it might be resolved. PBL is therefore a discovery learning experience where students work in small groups under the guidance of a tutor in order to solve an ill-structured problem, address a challenge or develop an artefact based on a problem of inquiry. Educational and psychological theories (see Section 2.2) provided a foundation for the practice and organisation of PBL in terms of mixing practical and theoretical work into one unified learning experience. Various models can be used to implement PBL, for example pure and hybrid PBL. It was also revealed that PBL relies on finding a solution to an ill-defined/structured problem by means of various carefully selected steps. As a result, PBL became one of the preferable teaching and learning strategies at the McMaster University in Canada and the Aalborg University in Denmark (see Table 2.1). The *problem* is a crucial part of designing a PBL experience and it is central to the understanding of the PBL approach that students should learn how to approach a problem of inquiry. Although most researchers agree that the problem in PBL is very important, there are other equally important aspects with regard to the problem that should be considered before introducing students to PBL. These are structuredness, complexity, relevance and the type of problem students are confronted with. Examples of ill-structured problems are dilemmas, scenario's and designs with no obvious resolution (see Section 2.3.2).

The main characteristics of PBL are students taking responsibility for their own tasks, empowered to conduct research, working in small groups and addressing ill-structured problems (see Section 2.4.1). The role of cooperation and teamwork is also important when applying PBL, as it closely resembles real-world settings where students need to share responsibility and liability with regard to the problem. In addition, PBL is also characterised by the use of reflection, since it helps to monitor and consolidate the learning that developed during the PBL task or project, and serves as reinforcement for refining metacognitive thinking. An essential characteristic of PBL is the key role of the facilitator, who assists in the development of problem-solving and high-order thinking skills, instead of using more traditional teaching methods such as lecturing. Assessment of PBL involves conveying evidence-based conclusions, developing problem-solving skills and enhancing team and communication skills (see Section 2.9).

7.4.3 What does Self-Directed Learning entail?

Malcolm Knowles described SDL as *internally regulated, self-esteemed, self-regulated and self-motivated behaviour*, *resulting from interest and satisfaction in activity* (see Section 3.2.2). Self-directed learning involves a process whereby students take responsibility for their own learning, set their own learning objectives, adapt their learning needs to a particular learning environment and assess their own learning outcomes. It was noted that theories of self-directed learning emerged during the investigation in the quest to find how students manage their own learning. It was, for example, noted by educational psychology researchers in the mid-twenties that there were significant differences between the learning results of children and those of adults, which resulted in the origination of theories such as andragogy, heutagogy, self-regulated learning and SDL.

Brockett and Hiemstra, Guglielmino and Warner argued that self-directed learning skills and lifelong learning are needed for professional, personal, organisational and family survival as well as for the survival of communities and different countries. This makes sense if one considers the vast amounts of available information, the rate at which new information is produced, the dynamic changes with regard to technology and the rate of globalisation. In order to become self-directed and be prepared for future demands, students should take *ownership* of their learning processes and educators are required to assist and facilitate them to develop as independent and responsible learners (see Section 3.3.1). The development of SDL in classes should have a favourable result with regard to life fulfilment, academic achievement and job satisfaction. There is conclusive evidence in the literature to highlight this contention regarding the value of SDL in classes. As a result, SDL promotes initiative, responsible learning, perseverance and the ability to make sound and informal decisions that are essential for future demands.

7.5 Conclusions regarding question 2: How can the implementation of hybrid problem-based learning in Mechanical Technology enhance pre-service teachers' higher-order thinking, practical knowledge and skills in the automotive discipline?

The question was answered by using mainly qualitative findings as emerged from the five themes (see Section 6.6.3). Some examples were selected as an indication of the hPBL steps that were employed as well as participants' experiences during the design and development of the four projects.

Conceptualise: "We shared ideas", "you hear the opinions of others", "Learning what I did not know", "I understand better now", "We helped each other as needed".

Define the problem: "We talk to each other and sort it out", "..when I lack knowledge I can learn from him,.."

Brainstorm (knowledge and needs): "We shared ideas", "…struggled for a long time to put an idea together", "Sometimes he will give you a better idea", "We will not argue….reason…for a new plan".

Categorise and structure ideas: "….we looked for the best solution…", "I can cope better with problems now".

Formulate and identify learning objectives: "We talk all the time about how we want to do it", "I used the planning to make the galvanised circuit in order to complete a real diagram".

Investigate, design and develop: "We did better research this time", "As you work and start building, you get other ideas that work better", "I liked the end product, the finished project looked good", "I like the creativity that is needed, my mind has widened".

Evaluate and reflect: "When I lack knowledge I can learn from him", "Learning what I did not know", "I understand better now, … it's just a learning process", my mind has widened", We shared the responsibilities 50/50", "We committed ourselves, we had to finish it", To figure out the steering system was the most difficult part, but a nice challenge", "I would have done better time planning", "We always shared the responsibilities, it was easier for the three of us".

Higher-order thinking is the ability to not only access knowledge or information, but rather how to manage, analyse and transform it into usable knowledge in practice. Examples of **higher-order thinking** include that students were able to: reason for a new plan, get other ideas that work better, figure out the steering system, "looked for the best solution" (analysis); "… my mind has widened", "I would have done better time planning", (evaluate); "…the finished project looked good", "I like the creativity that is needed" (create).

Students also developed essential **practical knowledge and skills** ('tricks of the trade') in the automotive discipline. These are knowledge, skills and competencies needed to do paper planning, anticipate logical steps and procedure, cut, saw, join, solder, weld, bend, shape, design, experiment, measure, and sometimes replan and employ new methods. Proof of this was found in the comments that students made, these included that PBL and project development enabled them to: complete projects to make them see and understand better, broaden their minds as a result of discovering new ideas on the go, help them to learn and develop knowledge and skills that they did not possess before, discover that you sometimes need the assistance of others; learn how to use equipment, implement theory to develop competencies as a result of endurance and dedication and improve people skills by means of collaboration and group work.

Form the abovementioned examples it is clear that participants developed higher-order thinking and practical knowledge and skills as a result of the two interventions.

The knowledge and skills listed below were development as part of hPBL. These are:

- Theoretical knowledge and skills regarding artefact development in project 1, 2, 3 and 4.
- Electrical, mechanical and safety content regarding the problem at hand.
- Knowing when and why to apply knowledge (make a selection of suitable materials to be used in a specific artefact such as choosing a material suited to fabricate a stub axle).
- Understand the importance that knowledge links with practice. The need to solve the problem at hand. Students learned new knowledge, skills and competencies during project development. They applied safety measures, used equipment and developed higher-order thinking.
- Judge against criteria (recommend suitable joining methods and material to be used). Decided on the equipment, processes and information needed. Found appropriate resources. Also part of the development of higher-order thinking.
- Find an alternative (critically evaluate alternatives to design and develop a challenging artefact). This also involves innovation, creativity and the integration of activities and processes.
- Team members developed essential group skills, communication and trust, they were committed and responsible for particular tasks to complete an artefact.
- Members developed self-directed learning skills such as taking initiative to manage their learning processes, formulating learning goals, being responsible for particular tasks and taking ownership of project design and development.

The development of higher order thinking (essential knowledge, skills and competencies) using hPBL steps in project development is displayed in Figure 7.2.

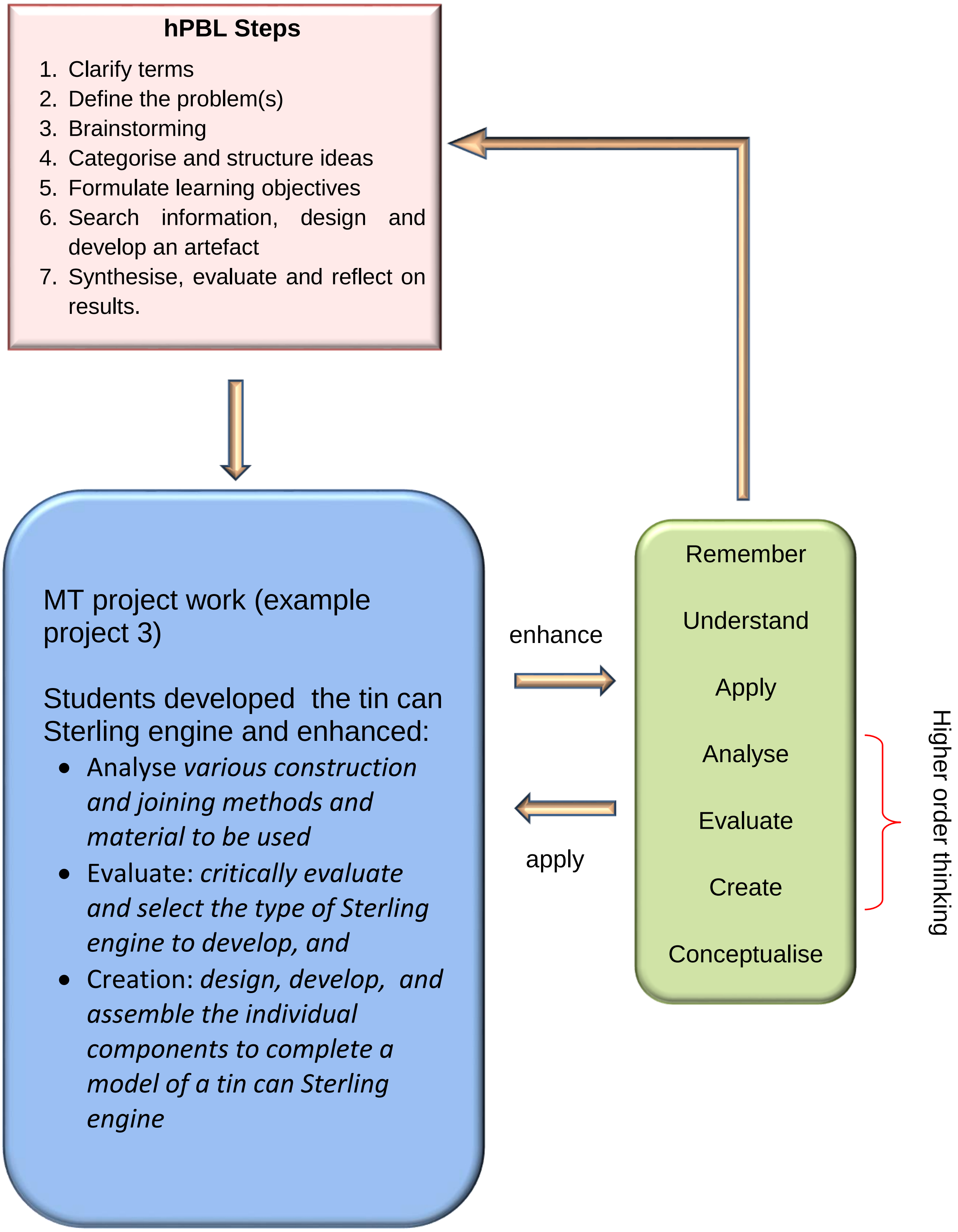


Figure 7:2: Development of essential knowledge, skills and competencies when applying hPBL

7.6 Reflection on question 3: To what extent can pre-service Mechanical Technology teachers enhance their self-directed learning in a problem-based context?

The quantitative results indicated that the mean SDL values slightly decreased from the pre-test 2017 to the post-test 2018 (235,19 to 226,47). Furthermore, changes in the constructs (awareness, learning strategies, learning activities, evaluation and interpersonal skills) were noted in some students' results, few had similar scores whereas others indicated an increase in one or more SDL constructs.

Changes in individual SDL total scores for 2017 and 2018 were displayed in Section 6.4.6. Most participants indicated high SDL scores (above 220) during 2017 and 2018. The value of the four projects should not be overlooked, as some students indeed improve their self-directedness to some extent. Further, a decline in the values could be due to the fact that participants underestimated the work and responsibilities involved in the projects. The lecturer reduced his involvement and assistance to participants during project 3 and 4 as they were supposed to take responsibility and ownership, do research, design and develop the projects on their own. The researcher analysed qualitative data to get a clear indication regarding students' hPBL experiences during the two interventions as well as the possibility of enhancing their SDL.

7.7 Reflection on the main research question: How can the implementation of hybrid problem-based learning in Mechanical Technology enhance pre-service teachers' self-directed learning?

From the quantitative data, it was clear that the mean SDL values slightly decreased from pre-test in 2017 to the post-test in 2018. Few students increased in one or more SDL constructs. The slight decline in values could be that participants underestimated the work involved in the 4 projects. It was also the students first experience with hPBL work. However, most participants indicated scores above 220, implying high SDL scores.

It was clear that the use of hPBL as a teaching-learning strategy enhanced students' SDL as emerged from the qualitative findings. The use of each of the hPBL steps in all 4 projects indicated the development of essential knowledge, skills and competencies such as higher-order thinking as well as problem-solving and practical skills in MT. Students conceptualised, defined and discussed the problem. They shared ideas and options and ‘learn what they did not know’. They sorted out problems, brainstormed and selected the best solution. Students clearly formulated learning objectives, searched and evaluated resources critically and this was followed with the design and development of artefacts. Students reflected on the hPBL experience: “they did better research, enjoyed developing the artefact” and noted: “I like the creativity that is needed, my mind has widened”. Further, they reflected, they shared responsibilities, committed themselves to complete the projects and added to the value of group work: “We always shared the responsibilities, it was easier for the three of us”.

Students developed higher-order thinking as they analysed, designed and developed these 4 artefacts. They got other ideas that work better, figured out the steering system, looked for the best solution and finished the projects on time. Students also developed essential practical knowledge, skills and competencies in the automotive discipline (planning, anticipate logical steps and procedure, practical tasks such as join, solder, weld, and bend). Therefore, participants better understood, broadened their minds, discovered new ideas and learned knowledge and skills that they did not possess before. Participants also improved on their people skills by means of collaboration and group work. From the abovementioned examples, it is clear that participants enhanced their SDL.

The researcher is of the opinion that both interventions were a success in addressing some workshop challenges and in enhancing students’ SDL abilities. A model to integrate hPBL in MTA classes is provided (see Figures 7.3). This is with regard to applying hPBL in MTA classes in order to enhance students’ SDL, practical knowledge and skills and contribute to the body of scholarship.

In Figure 7.3 the Maastricht seven jump approach served as basis for the MTA model, however, three steps were added in order to accommodate safety aspects, familiarisation with tools and equipment needed for the specific project and the exhibition of a finished project or artefact. The suggested MTA model thus consists of 10 steps to be used when applying hPBL in MTA classes and related subjects. Figure 7.3 highlights the use of a 10 step hPBL proses that includes mini-lectures, student activities and the proposed SDL results.

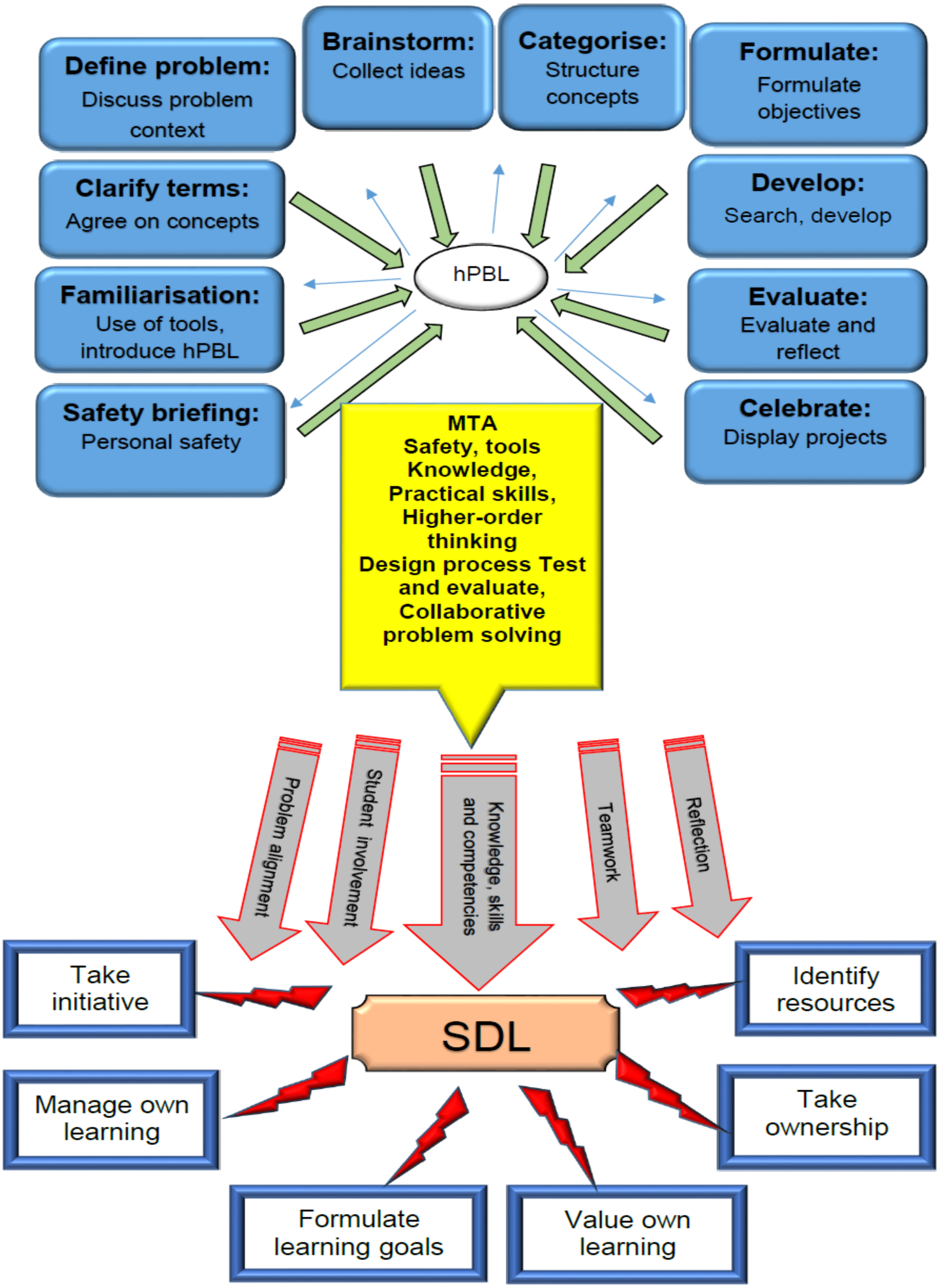


Figure 7:3: The 10 step MTA hPBL model

Source: Compiled by researcher

7.8 Conclusion

Participants developed knowledge, skills and competencies as they were challenged to design and develop 4 MT projects. The two interventions involved addressing some practical workshop challenges and required higher-order thinking. Students addressed and solved the problems in collaborative groups. A model to integrate hPBL in MTA was provided. This study contributes to the body of scholarship regarding the application of an adapted hPBL model for MT students. Futhermore, particpants' SDL were enhanced as a result of both interventions.

7.9 Recommendations

Implementation of the MTA model provided compliance regarding workshop practice, application of safety measures and the use of applicable equipment to a specific project. This is to ensure that the equipment can be used correctly, safely and with confidence. It is also important to work in small groups/teams (2 to 3 members) to ensure shared responsibility, meaningful conversations, resolving of personal differences and to optimise teamwork and responsibilities. Applying the hPBL approach may provide opportunities for MT students to develop various knowledge, skills and competencies in practical work as well as enhancing their SDL skills.

7.10 Summary of findings

The primary aim of this study was to implement hPBL in MTA to enhance students' self-directed learning as well as higher-order thinking and practical skills. It can be reported that some students' SDL were enhanced as a result of the implementation of hPBL by means of the development of the four practical projects. The research also provided an informed background regarding the essence of MT, PBL and SDL and recommended the use of the MTA hPBL model to apply PBL in MT related subjects with the aim to enhance the development of students' SDL skills.

7.11 Contribution of this study

This study contributed in terms of the particular implementation of hPBL in MT practical classes to enhance students' self-directed learning and to relieve workshop challenges and assisted them with the attainment of practical skills and higher-order thinking.

Moreover, this study contributed to the body of scholarship regarding the development of various knowledge, skills and competencies to foster MTA students' SDL. Furthermore, an integrated 10 step MTA hPBL model has been developed and is an important contribution to this study.

7.12 Limitations of this study

As this study and the results thereof unfolded, limitations and some challenges became apparent. These involve that appropriate practical projects should be carefully selected to ensure they are ill-structured, that some challenges involved time limitations that affected the quality of the projects. The sample size placed a limitation on the quantitative results and some students found the sudden move to hPBL in practical sessions somewhat challenging. Some participants initially experienced the hPBL approach challenging as they are used to more traditional methods of teaching.

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ADDENDUM A PROOF OF ETHICS APPROVAL

NORTH-WEST UNIVERSITY
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Institutional Research Ethics Regulatory Committee
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Email : Ethics@nwu.ac.za

ETHICS APPROVAL CERTIFICATE OF STUDY

Based on approval by the **Ethics Committee of the Faculty of Education Sciences (ESREC) on 04/08/2017** after being reviewed at the meeting held on **22/06/2017**, the North-West University Institutional Research Ethics Regulatory Committee (NWU-IRERC) hereby **approves** your study as indicated below. This implies that the NWU-IRERC grants its permission that, provided the special conditions specified below are met and pending any other authorisation that may be necessary, the study may be initiated, using the ethics number below.

Study title: Implementing hybrid problem-based learning in Mechanical Technology to enhance pre-service teachers' self-directed learning.

Study Leader/Supervisor: Prof M Havenga
Student: G Benadé

Ethics number:

N	W	U	-	0	0	4	8	4	-	1	7	-	A	2
Institution				Study Number						Year			Status	

Status: S = Submission; R = Re-Submission; P = Provisional Authorisation; A = Authorisation

Application Type: N/A

Commencement date: 2017-08-04 **Expiry date**: 2019-12-04 **Risk:** N/A

Special conditions of the approval (if applicable):

- Translation of the informed consent document to the languages applicable to the study participants should be submitted to the ESREC (if applicable).
- Any research at governmental or private institutions, permission must still be obtained from relevant authorities and provided to the ESREC. Ethics approval is required BEFORE approval can be obtained from these authorities.

General conditions:

While this ethics approval is subject to all declarations, undertakings and agreements incorporated and signed in the application form, please note the following:

- *The study leader (principle investigator) must report in the prescribed format to the NWU-IRERC via ESREC:*
  - *annually (or as otherwise requested) on the progress of the study, and upon completion of the project*
  - *without any delay in case of any adverse event (or any matter that interrupts sound ethical principles) during the course of the project.*
  - *Annually a number of projects may be randomly selected for an external audit.*
- *The approval applies strictly to the proposal as stipulated in the application form. Would any changes to the proposal be deemed necessary during the course of the study, the study leader must apply for approval of these changes at the ESREC. Would there be deviated from the study proposal without the necessary approval of such changes, the ethics approval is immediately and automatically forfeited.*
- *The date of approval indicates the first date that the project may be started. Would the project have to continue after the expiry date, a new application must be made to the NWU-IRERC via ESREC and new approval received before or on the expiry date.*
- *In the interest of ethical responsibility the NWU-IRERC and ESREC retains the right to:*
  - *request access to any information or data at any time during the course or after completion of the study;*
  - *to ask further questions, seek additional information, require further modification or monitor the conduct of your research or the informed consent process.*
  - *withdraw or postpone approval if:*
    - *any unethical principles or practices of the project are revealed or suspected,*
    - *it becomes apparent that any relevant information was withheld from the ESREC or that information has been false or misrepresented,*
    - *the required annual report and reporting of adverse events was not done timely and accurately,*
    - *new institutional rules, national legislation or international conventions deem it necessary.*
- *ESREC can be contacted for further information or any report templates via Erna.Greyling@nwu.ac.za or 018 299 4656*

The IRERC would like to remain at your service as scientist and researcher, and wishes you well with your project. Please do not hesitate to contact the IRERC or ESREC for any further enquiries or requests for assistance.

Yours sincerely

Prof LA Du Plessis
Digitally signed by Prof LA Du Plessis
Date: 2017.08.05 11:30:02 +02'00'

Prof Linda du Plessis
Chair NWU Institutional Research Ethics Regulatory Committee (IRERC)

ADDENDUM B QUESTIONS FOR FOCUS GROUP DISCUSSIONS

Questions for focus group discussions
1. What is your experience with the project?
2. Which facet or part of the project do you like the most?
3. How do you experience group work and do you work well together?
4. Which one of you is in charge?
5. How do you share responsibilities?
6. Who accepts liability?
7. Did you experience any conflict up till now?
8. How did you handle the conflict?
9. Have you noticed something you are going to improve on next time?
10. What have you have achieved this far?

ADDENDUM C SEMI-STRUCTURED INTERVIEWS

Semi-structured questions for interviews (open-ended)

1. Explain whether the development of the project in VTEE 222/VTEE 312 enabled you to take responsibility for your own work?
2. Explain whether all team members have taken responsibility for their tasks.
3. Give feedback regarding the assistance and support among your team members when developing the project
4. Give feedback regarding your team's personal interaction and communication
5. What problems or challenges did your team experience that interfered with achieving your aims?
6. Explain how your team solved or managed the problems or challenges (as mentioned above).
7. Reflect on the pace of your team's progress when planning and developing the project.
8. With regard to project-based learning, identify the most important advantages (according to you)
9. Explain whether the team meetings helped you to achieve your team's aims
10. Explain whether peer assessment helped you to achieve your team's aims.
11. Explain whether the project development enhanced your subject knowledge and skills.

ADDENDUM D WILLIAMSON'S QUESTIONNAIRE

Dear Student
Research on the improvement of education can be seen as a continuing process and it is a necessity in order to ensure quality teaching and learning at this institution. With this questionnaire, we aim to get an overview of your learning and study orientation in order to ensure that our teaching is of high quality. This forms part of a research project that aims to improve teaching strategies. Your participation is non-obligatory and will be confidential – the student number that you fill in on the multiple-choice form is solely for the purpose of comparing your answers before and after this course. It will not reflect negatively upon you if you decide to participate or not.

Answer each question as HONESTLY as possible

GENERAL INFORMATION

1. **Gender**

Male	1	Female	2

2. **Age**

18	1	19	2
20	3	21	4
22 – Older	5		

3. **Home language**

Afrikaans	1	English	2
Ndebele	3	N-Sotho	4
S-Sotho	5	Swazi	6
Tsonga	7	Tswana	8
Venda	9	Xhosa	10
Zulu	11	Other	12

4. **Preferable medium for teaching and learning**

Afrikaans	1	English	2

5. **Indicate your year group**

First-year	1	Second-year	2
Third-year	3	Fourth-year	4

6. **Indicate your average percentage of all your subjects in your previous academic year:**

44% and lower	1	45%-54%	2
55% - 59%	3	60% - 64	4
65% - 69%	5	70% - 74%	6
75% - 79%	7	80% - 100%	8

7. **Expected academic achievement in THIS subject:**

44% and lower	1	45%-54%	2
55% - 59%	3	60% - 64%	4
65% - 69%	5	70% - 74%	6
75% - 79%	7	80% - 100%	8

Response key: 1 = Never, 2 = Seldom, 3 = Sometimes, 4 = Often, 5 = Always						
8	I identify my own learning needs.	1	2	3	4	5
9	I am able to select the best method for my own learning.	1	2	3	4	5
10	I consider teachers as facilitators of learning rather than providing information only.	1	2	3	4	5
11	I keep up to date on different learning resources available.	1	2	3	4	5
12	I am responsible for my own learning.	1	2	3	4	5
13	I am responsible for identifying my areas of deficit.	1	2	3	4	5
14	I am able to maintain self-motivation.	1	2	3	4	5
15	I am able to plan and set my learning goals.	1	2	3	4	5
16	I have a break during long periods of work.	1	2	3	4	5
17	I need to keep my learning routine separate from my other commitments.	1	2	3	4	5
18	I relate my experience with new information.	1	2	3	4	5
19	I feel that I am learning despite not being instructed by a lecturer.	1	2	3	4	5

20	I participate in group discussions.	1	2	3	4	5
21	I find peer coaching effective.	1	2	3	4	5
22	I find “role play” is a useful method for complex learning.	1	2	3	4	5
23	I find inter-active teaching and learning sessions more effective than just listening to lecturers.	1	2	3	4	5
24	I find simulation in teaching and learning useful.	1	2	3	4	5
25	I find learning from case studies useful.	1	2	3	4	5
26	My inner drive directs me towards further development and improvement in my learning.	1	2	3	4	5
27	I regard problems as challenges.	1	2	3	4	5
28	I arrange my self-learning routine in such a way that it helps develop a permanent learning culture in my life.	1	2	3	4	5
29	I find concept mapping is an effective method of learning.	1	2	3	4	5
30	I find modern educational interactive technology enhances my learning process.	1	2	3	4	5
31	I am able to decide my own learning strategy.	1	2	3	4	5
32	I rehearse and revise new work.	1	2	3	4	5
33	I identify the important points when reading a chapter or an article.	1	2	3	4	5
34	I use concept mapping/outlining as a useful method of comprehending a wide range of information.	1	2	3	4	5
35	I am able to use information technology effectively.	1	2	3	4	5
36	My concentration intensifies and I become more attentive when I read complex study content.	1	2	3	4	5
37	I keep annotated notes or a summary of all my ideas, reflections and new learning.	1	2	3	4	5
38	I enjoy exploring information beyond the prescribed course objectives.	1	2	3	4	5
39	I am able to relate knowledge with practice.	1	2	3	4	5
40	I raise relevant question(s) in teaching-learning sessions.	1	2	3	4	5
41	I am able to analyse and critically reflect on new ideas, information or any learning experiences.	1	2	3	4	5
42	I keep an open mind to others’ point of view.	1	2	3	4	5
43	I prefer to take a break in between learning tasks.	1	2	3	4	5
44	I self-assess before I get feedback from instructors.	1	2	3	4	5
45	I identify the areas for further development in whatever I have accomplished.	1	2	3	4	5

46	I am able to monitor my learning progress.	1	2	3	4	5
47	I am able to identify my areas of strength and weakness.	1	2	3	4	5
48	I appreciate when my work can be peer reviewed.	1	2	3	4	5
49	I find both success and failure inspire me to further learning.	1	2	3	4	5
50	I value criticism as the basis of bringing improvement to my learning.	1	2	3	4	6
51	I monitor whether I have accomplished my learning goals.	1	2	3	4	6
52	I check my portfolio to review my progress.	1	2	3	4	6
53	I review and reflect on my learning activities.	1	2	3	4	5
54	I find new learning challenging.	1	2	3	4	5
55	I am inspired by others' success.	1	2	3	4	5
56	I intend to learn more about other cultures and languages I am frequently exposed to.	1	2	3	4	5
57	I am able to identify my role within a group.	1	2	3	4	5
58	My interaction with others helps me to develop the insight to plan for further learning.	1	2	3	4	5
59	I make use of any opportunities I come across.	1	2	3	4	5
60	I need to share information with others.	1	2	3	4	5
61	I maintain good interpersonal relationships with others.	1	2	3	4	5
62	I find it easy to work in collaboration with others.	1	2	3	4	5
63	I am successful in communicating verbally.	1	2	3	4	5
64	I identify the need for inter-disciplinary links for maintaining social harmony.	1	2	3	4	5
65	I am able to express my ideas effectively in writing.	1	2	3	4	5
66	I am able to express my views freely.	1	2	3	4	5
67	I find it challenging to pursue learning in a culturally diverse milieu.	1	2	3	4	5

(Self-directed learning of Teacher trainees, Adapted from Williamson, 2007)

ADDENDUM E MARKING RUBRIC 2017 / 2018

MARKING RUBRIC 2017 / 2018 **Projektitel/*ProjectTitle*** ____ **Lid 1: / *Member 1:* Student number** ______________________ A [ ] **Lid 2: /*Member 2:* Student number** ______________________ B [ ]			
PROJECT DOCUMENTS		**Mark**	**Comments**
1. TIME SCHEDULE (details and completeness)	**3**		
2. WEEKLY PROJECT SHEETS (details and completeness)	**20**		
PROJECT MANUAL			
1. Table of contents	**2**		
2. Introduction and aim of program	**2**		
3. Brief literature overview regarding the selected topic	**5**		
4. List proposed solutions	**15**		
5. Summary and conclusion	**2**		
6. Group reflection and experiences regarding problems, frustrations, solutions, advantages, and disadvantages of the project	**15**		
7. Bibliography	**3**		
GROUP ASSESSMENT AND CONTRIBUTION *(0,1,3,5)			(Max 5)
1. Deelnemer nommer / *Participation number*			
PROJECT TOTAL	**10**		

*Use the criteria below to judge both your and each group member's contribution by simply writing 0,1,3 or 5 next to the group member's name in the **third column**.*

0	1	3	4	5
Maak geen bydrae / *Made no contribution*	Bydrae was ondergemiddeld / *Contribution was less than average*	Maak 'n gemiddelde bydrae / *Made an average contribution*	Relatively good contribution / *Redelik goeie bydrae*	Lever 'n uitstaande bydrae / *Provided an outstanding contribution*

ADDENDUM F DETAIL OF PROJECTS DURING INTERVENTION.

Project 1. DESIGN AND BUILD YOUR OWN AUTO ELECTRICAL SYSTEM (Lights and controls)

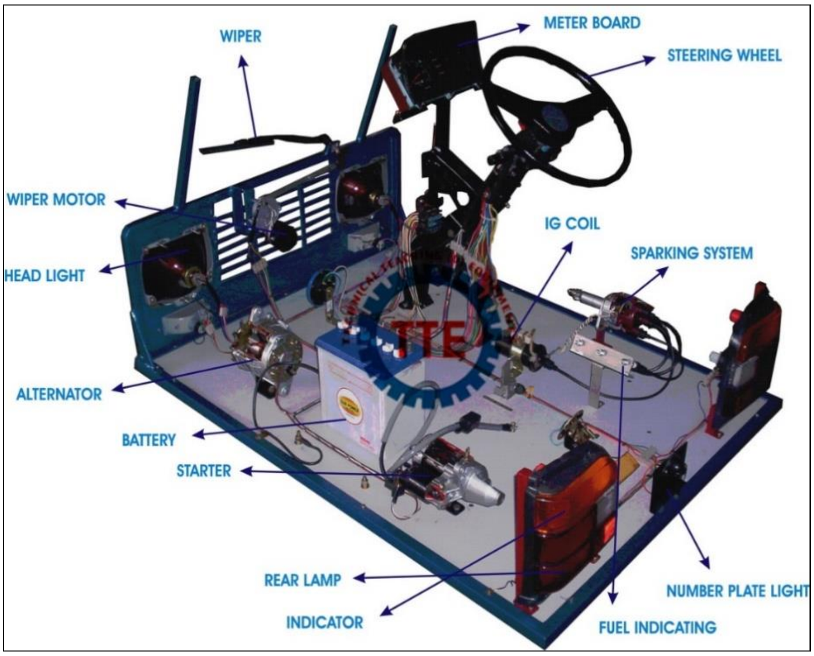
Students (participants) use their prior theoretical knowledge with regard to basic automotive electrical circuits to complete this project. If a group has an uneven number of participants one participant will have to rotate between groups. The project will be finished in more or less six weeks.

Students will be provided with PBL information and training, basic workshop safety information and training, project information (resources), a multi-meter, information, a galvanized steel body board, globes, connectors, relays, auto-wire, various switches, a fuse box, various fuses, isolation tape, various switches, flicker unit, ignition switch, pilot light, flicker switch, brake light switch and a design sheet.

Participants need to plan, design, develop, assess and finalise an auto electrical board simulating the basic vehicle electrical systems. (The project needs to meet basic specifications as provided by the tutor).

Specifications:

- **Spotlights to operate with switch and relay only**
- **Ignition key to switch system on**
- **Systems to be protected by fuses**



Example of an Auto electrical display board

(http://i3.ytimg.com/vi/dFWEc7Ytq44/mqdefault.jpg)

ADDENDUM G DESIGN AND BUILD A WIRE-FRAMED CAR

Project 2. DESIGN AND BUILD YOUR OWN WIRE FRAMED CAR (DRAADKAR)

(Joining methods, bending, shaping and basic designing)

Each student will complete his own project but he may call in the help of another participant to help with some of the steps. Students need to use their prior theoretical knowledge with regard to materials and joining methods to complete this project. There will usually be one group of six or seven participants working individually on this project. The project will be finished in six weeks.

Students will be provided with PBL information and training, basic workshop safety information and training, project information (resources), wire cutters, copper wire, solder, blow torch, plastic wheels, crimping tool, paint and a design sheet.

Participants need to plan, design, develop, assess and finalise a wire-framed car to simulate the body and steering layout of some vehicle. (The project needs to meet basic specifications as provided by the tutor [see Figure 1.2]).

Example of a wire-framed car.

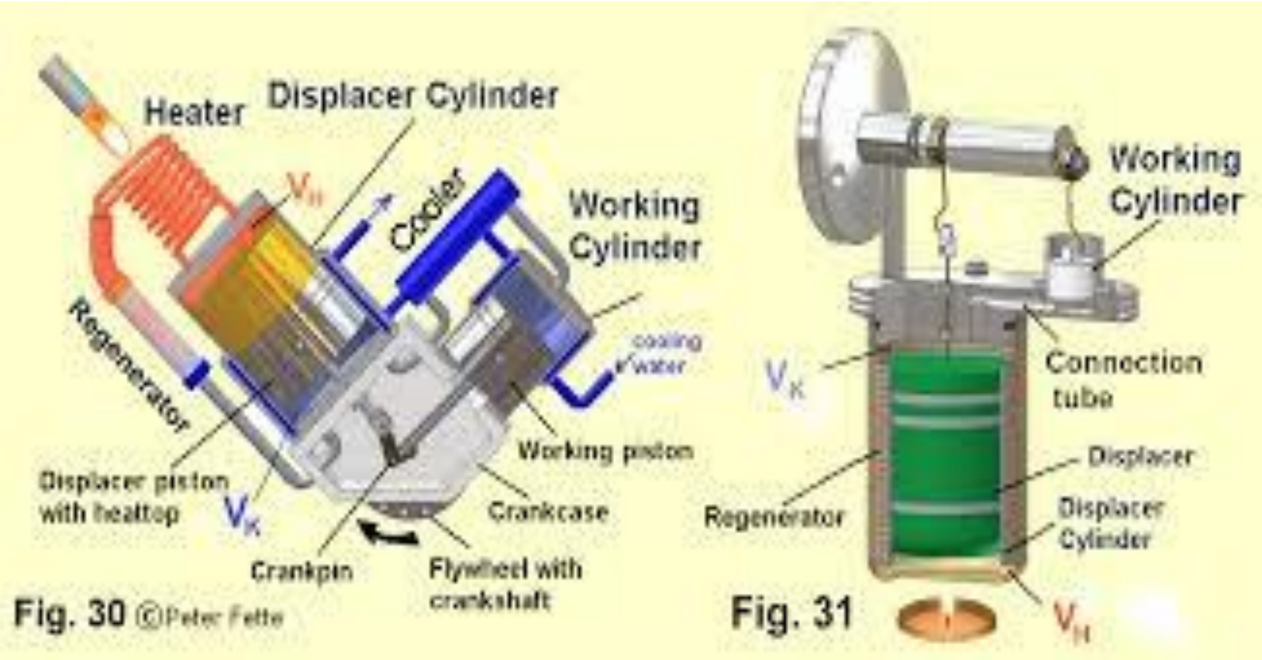
ADDENDUM H DETAIL OF PROJECTS I PART 2, 2018.

Project 3/4. <u>DESIGN AND BUILD YOUR OWN STIRLING ENGINE</u>
(Designing, joining, bending and shaping)

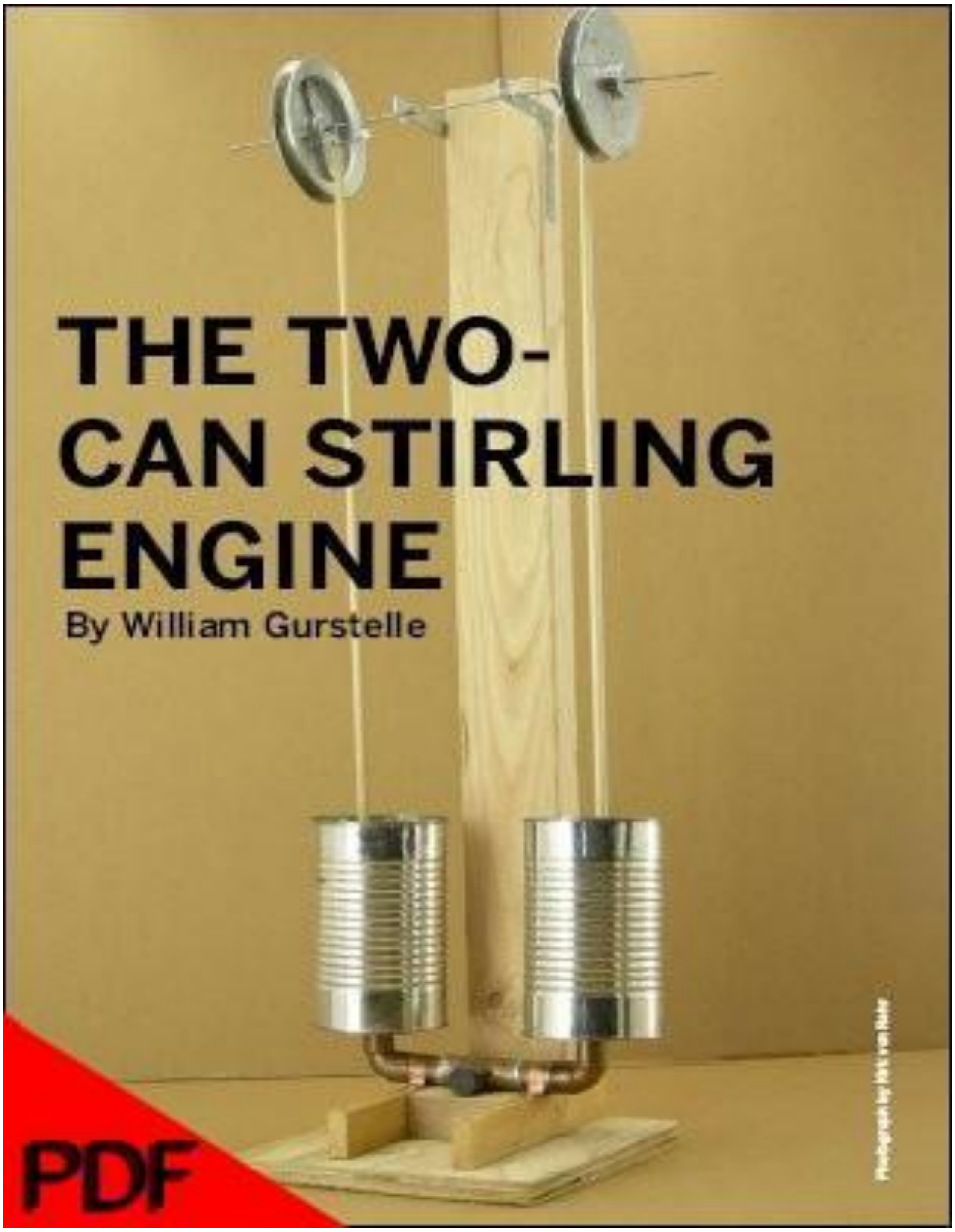
Students work in pairs (2 members) and they need to use their prior theoretical knowledge with regard to designing, bending, joining, and shaping etc. in order to complete this project. This project will be finished in six weeks. Each group (2 members) will complete one project. Students need to use their prior theoretical knowledge with regard to materials and joining methods to complete this project.

Students will be provided with PBL information and training, basic workshop safety information and training, project information (resources), wire cutters, copper wire, solder, blow torch, plastic wheels, crimping tool, paint and a design sheet.

Participants need to plan, design, develop, assess and finalise a working Stirling engine. (The project needs to meet basic specifications as provided by the tutor.



ADDENDUM I EXAMPLE OF STIRLING ENGINE



ADDENDUM J DESIGN AND BUILD AUTO ELECTRICAL SYSTEM

Project 4/4. <u>DESIGN AND BUILD YOUR OWN AUTO ELECTRICAL SYSTEM</u>
(Auto electrical: Ignition, alternator and starter)

Students work in groups with 3 to 4 members and they need to use their prior theoretical knowledge with regard to basic automotive electrical circuits to complete this project. This project will be finished in four weeks.

Students will be provided with PBL information and training, basic workshop safety information and training, project information (resources), a multi-meter, information, an ignition switch, connectoauto-wirewire, isolation tape, pilot light, and a design sheet.

Participants need to plan, design, develop, assess and finalise the auto electrical connections which will allow the 4Y engine to start and for the alternator system to charge using a pilot light as signal. (The project needs to meet basic specifications as provided by the tutor).

ADDENDUM K INFORMED CONSENT

NORTH-WEST UNIVERSITY ®
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participant information and consent form

I herewith wish to request your consent to participate in this research, which involves students from the North West University. Before you give consent, please acquaint yourself with the information below.

The details of the research are as follows:

TITLE OF THE RESEARCH PROJECT: Implementing hybrid problem-based learning in Mechanical Technology to enhance pre-service teachers' self-directed learning.

PROJECT SUPERVISOR: Prof H.M. Havenga
ADDRESS: Building B10, Potchefstroom campus
CONTACT NUMBER: 018 299 4281

MEMBER OF PROJECT TEAM PhD-Student: Mnr. G.P. Benadé
ADDRESS: B9, Potchefstroom campus
CONTACT NUMBER: 018 299 4235

This study has been approved by the Ethics committee of the Faculty of Education of the North-West University and will be conducted according to the ethical guidelines of this committee.

What is this research about?
The main aim of this study is to determine how the implementation of hybrid problem-based learning (hPBL) in Mechanical Technology (MT) can enhance pre-service teachers' self-directed learning.

The sub-aims are:

The sub-questions were the following:

1. What does Mechanical Technology, problem-based learning and self-directed learning entail?

2. How can the implementation of hybrid problem-based learning in Mechanical Technology enhance pre-service teachers' higher-order thinking, practical knowledge and skills in in the automotive discipline?

3. To what extent can pre-service Mechanical Technology teachers enhance their self-directed learning in a problem-based context?

The questions were answered by means of a thorough literature review and by empirical research.

Participants

All second year MT education students enrolled in the VTEE module.

What is expected of <u>you</u> as participant?

1. To work in groups and complete two MT projects as part of the intervention.
2. Complete a questionnaire twice, once at the start of the project and again at the end of the intervention.
3. Take part in focus group discussions and keep a journal.
4. Submit yourself to a 15-20 minute interview if you are selected.
5. You may be included in video and sound recordings as well, as other recordings as part of the normal workshop activities during the intervention.

Benefits to you as a participant

1. Gain confidence, self-directedness and obtain knowledge and practical skills with regard to the applicatiproblem-solvingving.
2. Learn to work effectively in a group and manage your team.
3. Manage all phases of project development.
4. Apply problem-based learning as a teaching-learning strategy.
5. Become a confident MT teacher.

Risks involved for participants

1. Small risk or minor injuries like minor cuts or burns if you do *not* apply all safety regulations correctly.

Confidentiality and protection of identity

1. You will be part of a group working under the guidance of a facilitator/tutor and therefore you will be in a protected environment as no outsiders will visit the class or interfere in any way.
2. All your credentials and personal information about your progress during the intervention will be accessible only to the lecturer and the study leader, however reference will be made to you by only using pseudonyms (Participant 1 etc.).
3. Data with regard to your project work will be kept confidential at all times.
4. Results will be stored in a secure location and kept for 5 – 7 years.

Dissemination of findings

Research findings will be published in a PhD dissertation and articles. Findings may also be implemented in future MT training.

If you have any further questions or enquiries regarding your participation in this research, please contact the researcher for more information.

ADDENDUM L DECLARATION OF PARTICIPANTS

By signing below, I …………………………………..…………. student number ……………….. agree to take part in a research study entitled:

Implementing hybrid problem-based learning in Mechanical Technology to enhance pre-service teachers' self-directed learning.

I declare that:

- I have read this information and consent form and understand what is expected of me in the research.
- I have had a chance to ask questions to the study leader and all my questions have been adequately answered.
- I understand that taking part in this study is voluntary and I have not been pressurised to take part.
- I may choose to leave the study at any time and will not be penalised or prejudiced in any way.
- I will take part in the development of two MT projects since this is compulsory in the VTEE module.

Select one of the following:

☐ I will take part in the research study (as indicated with an 'X')

☐ I will not take part in the research study (as indicated with an 'X')

A	

My number as participant

B	

Signed at (place)____________________________on (date) ______/______/2017

Signature of participant

Signature of witness

ADDENDUM M SDL ASSIGNMENT

Assignment 15/08/2017, semester 2, 2017 (VTEE 222).

General information

- This assignment must be completed in the period before the official WIL period begins thus week from 17 to 21 July 2017.
- The assignment must be handed in on or before Tuesday 15 August.
- The outcomes that you have to achieve in this assignment are important for the work project that you will be doing in the second semester.

Technical requirements for assignments

- Do the questions on a computer
- Headings must be numbered numerically, not alphabetically
- Structure your assignment logically, using appropriate headings and subheadings.
- Present your work in legible form, preferably in 1.5 spacing in an 11 or 12 point
- Font size (Arial 11 or 12)
- No photocopying or printing directly from the internet will be accepted
- Give each assignment a title page

Proceed as follows:

Use the information in the two sources (Maurice Gibbons and Brockett & Hiemstra) placed on Efundi and answer the questions below. Also do a further media or internet search to supplement the sources.

Questions

1. Explain the following concepts in your own words:

1.1. Learning Needs

1.2. Self-motivation or intrinsic motivation

1.3. Education Strategy

1.4. Learning Style

1.5. Group Work

2. Write a short paragraph and define each of the following:

2.1 Self-directed learning (SDL)

2.2 Problem-Based Learning (PBL)

2.3 Cooperative learning

3 Briefly explain how you learn (personally)

ADDENDUM N PROGRAM OUTCOMES AND ADMISSION REQUIREMENTS FOR BED TECHNOLOGY (NWU)

Outcomes

COMPILATION OF QUALIFICATION: BEd SENIOR AND FURTHER EDUCATION AND TRAINING PHASE

Programme Outcomes / *Programuitkomste*

The students of the Senior and Further Education and Training phase are expected to:

Daar word van Senior- en Verdere Onderwys en Opleidingfase-studente verwag om:

- Solve problems, particularly those pertaining educational matters, through critical and creative thinking.

Deur kritiese en kreatiewe denke, veral op die gebied van opvoedkundige sake, probleme op te los.

- Work effectively (in a team) with other teachers, with parents, community members and all other stakeholders regarding education.

Effektief (in 'n span) saam met ander onderwysers, met ouers, gemeenskapslede en alle ander belanghebbendes rakende onderwys, te werk.

- Organize and manage their classrooms and their time regarding school work and extra-mural activities responsibly and effectively.

Hul klaskamers en hul tyd, met betrekking tot skoolwerk en buitemuurse aktiwiteite, verantwoordelik en effektief te organiseer en te bestuur.

- Display a frame of mind that is inclined to research, thus to collect, analyse, organise and critically evaluate information regarding educational matters.

'n Navorsingsingesteldheid te toon, dus om inligting rakende opvoedkundige aangeleenthede te versamel, analiseer, organiseer en krities te evalueer.

- Demonstrate effective communication skills, both outside the classroom and in, by, among others, making use of the best educational technology at their disposal.

Effektiewe kommunikasievaardighede, beide binne en buite die klaskamer te demonstreer deur, onder andere, gebruik te maak van die beste opvoedkundige tegnologie tot hul beskikking.

- Demonstrate understanding that the world in general and the world of education consist of a set of related systems (education authorities, school management, teachers, learners, parents, and other community members) by taking all the stakeholders concerned into account, when solving a problem.

95

Begrip dat die wêreld in die algemeen en die wêreld van onderwys uit 'n stel verwante stelsels (onderwysowerhede, skoolbestuur, onderwysers, leerders, ouers en ander lede van die gemeenskap) bestaan, demonstreer deur al die betrokke belanghebbendes in ag te neem wanneer hulle probleme op los.

- Develop learners' entrepreneurial skills by giving them as many opportunities as possible to practice these skills.

Leerders se entrepreneursvaardighede te ontwikkel, deur hulle soveel om hierdie vaardighede te oefen.

Admissions

(Mechanical Technology Education), **4BN-J18** (Civil Technology Education), and **4BN-J19** (Electrical Technology Education) are the following:

- Mathematics pass rate of at least 50% in the Gr 12 examination and/or
- Physical sciences, Technology subjects (Mechanical or Civil or Electrical Technology) as well as Engineering Graphics and Design are a recommendation to enrol in the different programs.

Students that **do not meet the minimum requirements,**

- who have passed Mathematics in Gr 12 with at least 40%, or
- who have passed Mathematical Literacy in Gr 12 with at least 50 % with any Technology subjects in Gr 12, or
- who have passed Technical Mathematics with at least 50 % in Gr 12, with any Technology subjects in Gr 12, that can replace Mathematics or Mathematical Literacy,

may be allowed entry into these programmes on condition that he/she passes the **bridging modules** MTEC 111 and MTEC 121 during the first two years of study.

Die programme word saamgestel uit die modules wat oor vier jaar versprei is. Alle programme en modules word op kontak en afstand aangebied, behalwe in gevalle aangedui as "slegs kontakstudente".

***Vereistes** vir studente wat wil registreer vir programme **4BN-J17** (Meganiese Tegnologie Onderwys), **4BN-J18** (Siviele Tegnologie Onderwys) en **4BN-J19** (Elektriese Tegnologie Onderwys) is as volg:*

- *Wiskunde slaagsyfer van minstens 50% in die Gr 12-eksamen en / of*
- *Fisiese wetenskappe, Tegnologie vakke (Meganiese- of Siviele- of Elektriese Tegnologie) sowel as Ingenieursgrafika en Ontwerp is 'n aanbeveling om in die verskillende programme in te skryf.*

*Studente wat **nie aan die minimum vereistes voldoen nie,***

- *wat Wiskunde in Gr 12 met minstens 40% geslaag het, of*
- *wat Wiskundige Geletterdheid in Gr 12 met minstens 50% geslaag het met enige Tegnologie vakke in Gr 12, of*
- *wat in Tegniese Wiskunde met minstens 50% in Gr 12 geslaag het, met enige Tegnologie vakke in Gr 12 wat Wiskunde of Wiskundige Geletterdheid kan vervang,*

*mag toegelaat word tot hierdie programme op voorwaarde dat hy/sy die **oorbruggingsmodules** MTEC 111 en MTEC 121 gedurende die eerste twee studiejare slaag.*

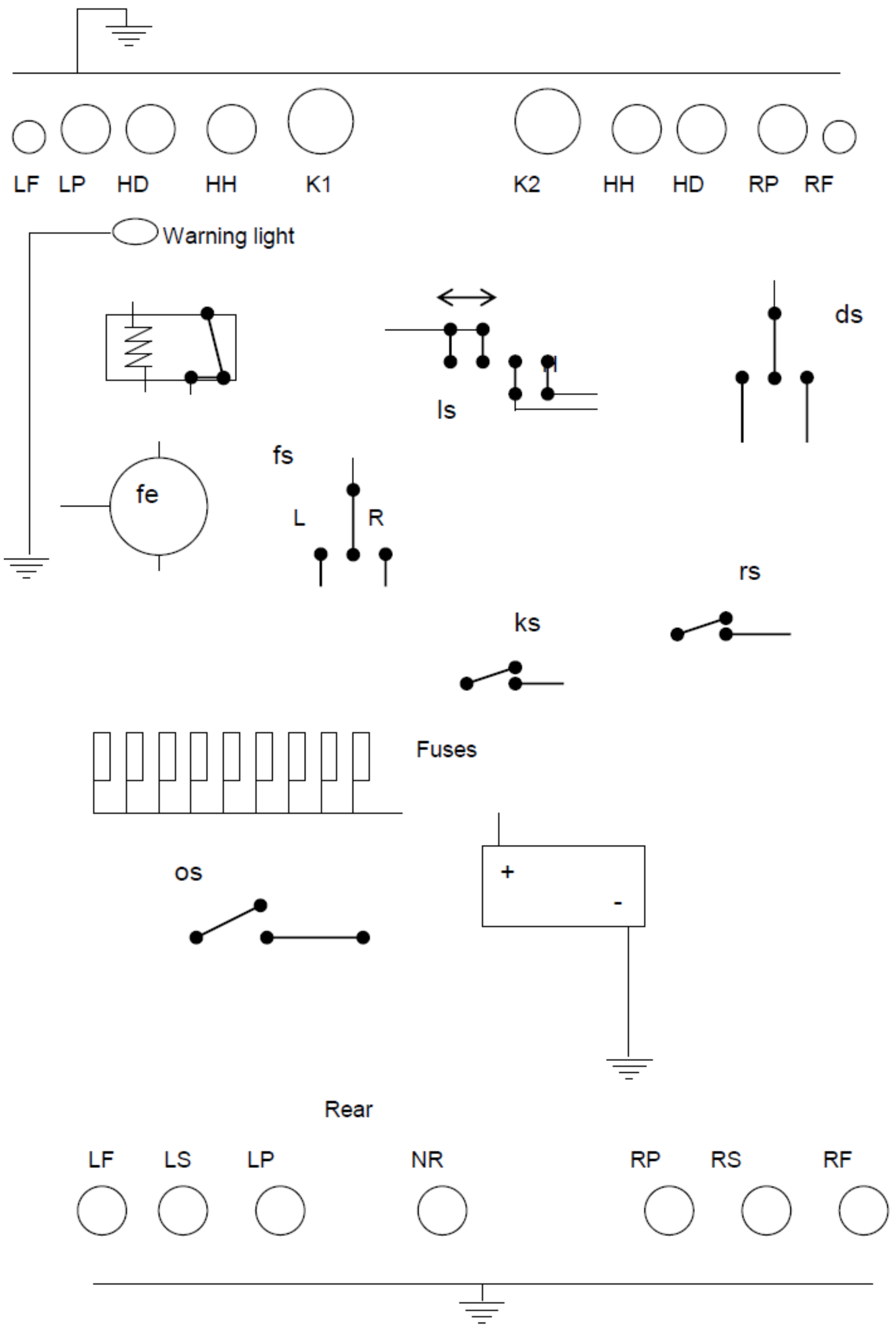
ADDENDUM O PROJECT SHEETS

VTEE 312: *Weekly Project Sheet: Complete in DETAIL ONE per team*	***Date:*** __ /__ / 2018
GROUP NUMBER: ________ : ***members nrs.*** ______________________________	
1. Discuss your teams' RESPONSIBILITIES AND PROGRESS up to now and refer to: **a) Project planning** **b) Project design** **c) Project development (techniques e.g welding)**	
2. Specify EACH MEMBERS' OWN responsibilities / activities today. Please mention all **Member 1:** __________________________	
3. Give feedback regarding the assistance and support among your team members when working on project activities. Please be honest. /	
4. Give feedback regarding your team's personal interaction and communication when working on project activities. Please be honest. /	
5. Which problems or challenges did your team experience in not achieving your aims or project activities? Please be honest	
6. Explain how your team has solved or managed the problems or challenges (No 5 above).	
7. Reflect on the pace of your team's progress in project development	
8. Specify which information you searched for regarding the development of your project. List all the resources that you have used.	

ADDENDUM P TEMPLATE FOR PLANNING WIRING DIAGRAM

1

LF-RF = flickers left and right LP- RP = Park lights HD = Main lights- low beam (dim)
HH = Main lights- high beam (bright) K1+K2 = Stot lights LS-RS = Brake lights left and right
NR = Number plate light
FE = flicker unit LS = Light switch DS = Dim switch FS = Flicker lever
KS= Spot light switch OS= Ignition switch RS= Brake light switch



ADDENDUM Q SAFETY TRAINING (EXAMPLE)

Safety in the workshop

1. ***Legislation****: Employees and employers are protected by law.*

1.1 ***Original Ac****t: Act on Factories, Machinery and Building Work of 1941. Later amended to Occupational Health and Safety Act, No 85 of 1993.*

1.2 *An* ***accident*** *is an unforeseen and uncontrolled event which is caused by an unsafe* ***act*** *or* ***condition****.*

ADDENDUM R EXAMPLE OF VERBATIM TRANSCRIPTIONS

29 Augustus 2017 B6 en B8 – draadkar interview 1

1. Wat is julle belewenis met die projek?
Baie lekker en ‘n nuwe ervaring, ons het nog nie voorheen ‘n nuwe draadkar gebou nie.

2. Van watter faset hou julle die meeste?
Die soldeerwerk

3. Kommentaar oor die ontwerp?
Dit is lekker om my eie idees te volg en my eie ding te doen en ‘n kreatiewe ontwerp te maak en nie van iets af te werk nie.

4. Julle werk tans aan B6 se projek. Het julle al iets raakgesien wat julle anders gaan doen in B8 se projek?
Ja, minder laste maak

5. Hoe ervaar julle dit om in ‘n groep te werk?
Baie effektief. B8 doen al die moeilike buigwerk en B6 doen die fyn afrondwerk. B6 doen die fyn buigwerk en veilwerk.

6. Is een van julle in beheer van die span?
Nee, ons albei werk maar saam.

7. Watter probleme het julle al ervaar?
Die draad is baie hard en moeilik om te buig.
Het julle ‘n manier gevind hoe om dit reg te kry? Ja

8. Kom julle oor die weg, of is daar konflik? Indien wel, hoe hanteer julle dit?
Ons praat maar daaroor en sorteer dit gou uit. Die werk moet gedoen word.

9. Hoe verdeel julle verantwoordelikhede?
Ons het vinnig agter gekom wie is goed met wat. Ons het dadelik gesien ek is goed met die 90° buigwerk en hy die groter buigwerk, toe sê ons sommer dadelik dat hy dit moet doen en ek my deel doen.

9. B6, lewer jy meer bydrae as B8?
Nee, ons albei doen ewe veel. Die werk word min of meer 50/50 verdeel.

10. Het julle verskille ten opsigte van julle werk- en dinkmetodes?
B6 is nie gepla oor presiesheid nie, dit pla hom nie as goed nie presies simmetries is nie. Waar B8 perfeksionisties is en fyn detail haar pla. B6 wil die werk klaarkry en B8 wil kwaliteit werk lewer.

11. Wat het julle vandag bereik wat julle nie laasweek kon doen nie?
Die week het ons afronding gedoen, ons weet hoe om alles te doen, so ons werk vinniger.