Cumulative knowledge building in distance and contact sessions: A comparison of two lessons in Technical Sciences on the topic of semiconductors for Grade 12.

A research project submitted to the Faculty of Humanities, University of the Witwatersrand in partial fulfilment of the requirement for the degree of Masters in Education by combination of coursework and research report

By

Angeline Duma
Student number: 1143754
Protocol number: 2020ECE030M

Supervisor: Dr Emmanuel Mushayikwa

Johannesburg, South Africa
April 2021

COPYRIGHT NOTICE

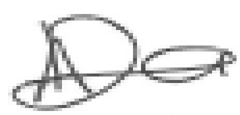
ABSTRACT

The Professional Teaching Standards (PTs) in South African schools have established cumulative knowledge building as the core of the teachers' work. However, cumulative knowledge building is often understudied raising concerns for intervention. The main aim of the study was to gain insight of how cumulative knowledge building takes place in a lesson taught through distance and contact sessions. Legitimation Code Theory (LCT) was used as a conceptual framework, with a specific focus on semantic density (SD) and semantic gravity (SG). The study employed a qualitative case study approach, with pre-recorded video observations serving as the primary data collection method and document analysis serving as a supplement. The main findings of the study revealed that the contact lesson offers greater opportunities for cumulative knowledge building mainly because of the extended semantic gravity range and the teachers' ability to develop learners as knowers of science. The findings suggest that there is a need for distance teachers to adopt strategies that can extend the semantic gravity range. The findings raised more questions about the extent to which distance lessons may cater for learners' engagement and the processes of building learners into the knowers of science. Given the current state of our education as a result of COVID 19, it is crucial for distance lessons to contribute significantly to cumulative knowledge building. The findings of the study will significantly add to the limited knowledge and consequently influence the pedagogical strategies that teachers employ in their lessons to cater for the required demands in the education sector.

Key words: Professional Teaching Standards, cumulative knowledge building, Legitimation code theory, semantic gravity (SG), semantic density (SD), semantic ranges, COVID 19, contact sessions, distance sessions.

DECLARATION

I **ANGELINE DUMA (1143754)** declare that this research study is my own work. It has not been submitted before for any other degree or examination in any other university. All the work taken directly from other works has been cited accordingly and the full list of references has been provided. I fully understand that the University of the Witwatersrand will take disciplinary action against me if evidence suggests that this is not my own unaided work or that I failed to acknowledge the sources of the ideas or words in my writing.



………………………………………………………………………………

University of the Witwatersrand, April 2021

Protocol number: 2020ECE030M

ACKNOWLEDGEMENTS

I would like to direct my sincere gratitude to my supervisor: Dr Emmanuel Mushayikwa for his professional guidance, support, and profound advices. You have been the greatest supervisor and this study would not have been possible without you. To my sister, Amanda Duma, you have been my pillar of strength. Thank you so much for the emotional and spiritual support. To my entire family, many thanks for the constant words of encouragement, this journey has not been easy, however with the love, support and patience from you, I was able to walk through it till the end. Last but not least, I would like say thank you to my academic companions: Mary Nkuna and Timeyo Kanyinji for accompanying me through this journey.

Many thanks to the National Research Foundation (NRF) for financial assistance in completing this degree.

ABBREVIATIONS AND ACRONYMS

FET	Further Education and Training
CAPS	National Curriculum and Assessment Policy Statement
NSC	National Senior Certificate
NQF	National Qualifications Framework
DoE	Department of Education
SACE	South African Council for Educators
UNESCO	United Nations Educational, Scientific and Cultural Organization
PTs	Professional Teaching Standards
COVID 19	Coronavirus
LCT	Legitimation Code Theory
SG	Semantic Gravity
SD	Semantic Density
SG−	Weak semantic gravity
SG+++	Stronger semantic gravity
SD−	Weak semantic density
SD+++	Stronger semantic density
SG↑	Strengthening semantic gravity
SG↓	Weakening semantic gravity
SD↓	Weakening semantic density
SD↑	Strengthening semantic density

Table of Contents

LIST OF FIGURES

LIST OF TABLES

LIST OF IMAGES

LIST OF APPENDICES

CHAPTER 1: INTRODUCTION AND ORVIEW OF THE STUDY

1.1 Introduction

Education is an essential element which plays an enormous role in the modern industrialized world. Many scholars would agree with me when I suggest that the acquisition of high-quality education is the primary objective of the education sector. While education is important, there are factors such as pandemics that can impede learning and teaching, impacting the overall education. Bao (2020) comments that the COVID 19 pandemic has wrecked and stopped the wheel of education forcing the world to move to distance platforms such as online teaching. According to UNESCO (2020), the COVID 19 pandemic has left more than billions of students unable to attend schools and universities. Universities and schools in South Africa have been closed for an unspecified period of time to prevent face-to-face interactions so as to control the virus. According to Moloi (2020) the government of South Africa has instructed institutions and schools to stop contact teaching for most of their students, forcing them to turn to distance teaching almost overnight. Daniel (2020) argues that the COVID 19 pandemic poses an enormous challenge to the educational systems which have relied heavily on contact teaching. In this unstable situation, distance teaching has shown some rays of hope that could somehow start the wheel of education (Mondol & Mohiuddin, 2020).

Although this is an interim, temporary measure, the question arises whether the knowledge-building of contact lessons can be similar or different from those given by distance teaching, such as recorded lessons. Cumulative knowledge building is of paramount importance in the education sector, whether the teaching occurs in contact or distance measures. Understanding how teachers cumulatively build knowledge in technical science classrooms using the semantics dimension of legitimation code theory (LCT) in both distance and contact lessons may be worthwhile to explore. Cumulative knowledge building, is not limited to technical sciences; its significance can be seen in a variety of disciplines.

The purpose of this research project is to compare how cumulative knowledge building occurs in contact and distance lessons for Grade 12 technical sciences on the topic of semiconductors. In this study, distance sessions refer to teaching and learning that is usually conducted through technological measures while contact sessions speaks to a classroom scenario where a teacher conducts a lesson with the presence of learners.

1.2. Background and context of the study

In the midst of the COVID 19 pandemic, millions of teachers started teaching in front of computers and their students had to stay at home and take the online courses (Bao, 2020). For example, in South Africa, talks about online learning, use of television and radio for revision began to occupy the educational sector corridors immediately after the lockdown that directly resulted in school shutdowns (Moloi, 2020). Higher institutions, resorted to the use of Microsoft Teams, Skype, Zoom Meetings and WhatsApp groups to facilitate teaching. In addition, the basic education department released study materials such as text books, worksheets, revision booklets and study guides on their website. The website provided links to previous Grade 12 exam papers for revision purposes.

Although not much has been documented regarding distance teaching and learning in technical sciences on the topic of semiconductors, a study conducted by Hassenburg (2009), explored the general feasibilities of distance learning and teaching in relation to contact teaching. The study found that distance learning also has advantages, indicating that there is hope for it. Given the fact that little has been documented about distance learning in technical sciences on the topic of semiconductors, a study that looks deeper into the insights of knowledge building in teaching the topic of semiconductors in both distance and contact sessions is required to gain a better understanding of each mode of lesson delivery.

1.3. Rationale of the study

Section 2 of the National Curriculum Policy Statement (CAPS) for technical sciences Grade 10 - 12 states that the aims of technical sciences is to prepare learners for further education training (FET), employment and socio-economic development. It is argued that technical sciences will promote skill development in the field of technology, thus promoting economic growth and social well-being of more citizens in South Africa. It is important however, to recall that technical subjects such as technical mathematics and technical sciences were only introduced in 2019 by the Department of Education (DoE) to form part of the subjects that learners are likely to pursue in Grade 10 to Grade 12. This makes these subjects relatively new in the curriculum and their role is without a doubt significant. Even though the curriculum stresses the importance of learning technical sciences in South African schools- it remains notable that not much has been documented on the teaching and learning of technical sciences mainly because the subject is relatively new in the South African curriculum. For this reason, my research aims to broaden the scope on the teaching and learning of the subject through understanding how cumulative knowledge building takes place.

Technical sciences influence technological developments; for example, looking at the topic of semiconductors which deals with the field of electronics and electronic products which are of relevance to todays' world, surely, we recognize the need to understand this branch of technology which directly impacts scientific and technological developments thereby impacting our daily lives. Earlier studies on semiconductors, argue that due to the link of semiconductors with technological advancement, it is necessary for high school learners to acquire a robust understanding of this technological discipline at an early age (Garcia-Carmona & Criado, 2009).

In addition, the topic of semiconductors falls under the theme of matter and materials with a weighting of 27% in Grade 10 making it the second topic with the highest ranking while it comprises a weighting of 13% in Grade 12 technical science curriculum, making it the third highest amongst the six knowledge areas that technical science comprises. As argued by the CAPS document for technical sciences, Grade 10-12, technical sciences looks at the progression of content and context from simple to complex- this is the case with the topic of semiconductors. In Grade 12 learners explore this topic in greater detail drawing from the knowledge bases provided for in Grade 10. The fact that this topic shows this great continuity as compared to other topics reveals its importance, thus marking the topic fundamental to explore. An understanding of cumulative knowledge building may increase the chances of performance for the learners in the topic of semiconductors.

The focus on Grade 12 lies on the realization that the Grade 12 level is a vital year in high school because it determines whether learners continue to higher education phase or not (Edwards, 2010). The success of learners depends on the results obtained in Grade 12 which gives learners the National Senior Certificate (NSC) which is a qualification at level 4 on the National Qualification Framework (NQF). A study that focuses on the teaching and learning of Grade 12 learners is without a doubt worth partaking in as it would maximize the chances of learners' success in the future.

This study seeks to gain insight of how cumulative knowledge building takes place in both contact and distance sessions such as online learning. The focus on contact and distance sessions stems from the instant shift from contact teaching to distance teaching as a result of the COVID 19 pandemic. Focusing on these two distinct modes of teaching and learning will help reveal the feasibility of each mode thereby influencing the future teaching of the topic of semiconductors. Perhaps we may find our teaching being significantly aligned to a blended learning situation where learners receive significant portions of instruction through both contact and distance means (Bakia, Shear, Toyama & Lesseter, 2012).

1.4 Problem statement

The South African Council for Education (SACE) along with the Professional Teaching Standards (PTSs) suggests that knowledge building is the core of the teachers' work. In Strand 5 of the PTSs, it is stated that teaching is fundamentally connected to teachers' understanding of the subject/s they teach. This includes understanding the subject/s they teach as bodies of knowledge in which important concepts are connected to one another. It also involves teachers understanding how learners' process and present information in the subject/s they teach. Teachers also need to understand how subject knowledge can be applied to interpret and address real-world issues (SACE final draft PTS for Gazette, 2018). Cumulative knowledge-building refers to learning that expands and connects prior knowledge with knowledge generated in different contexts and at different times (Maton, 2014). The above points speak to the importance of knowledge building as the heart of the teachers work.

Although knowledge building remains at the core of the teachers' work as stipulated by the South African Council for Education (SACE), it is often understudied even though it plays a huge role in teaching and learning. Studies conducted by Maton (2013) and Scardamia and Bereiter (2020) revealed the importance of knowledge building in teaching, however little research developments have been done on knowledge building especially on the topic of semiconductors. This study aims to broaden the scope of teaching the topic of semiconductors, and to pave the ground for an understanding of knowledge building within the topic of semiconductors through distance and contact sessions.

1.5 Purpose of the study

The purpose of this study proceeds in three fold. Firstly, it is to gain insight of how cumulative knowledge building takes place in a lesson taught through distance and contact sessions. Secondly, is to describe the similarities and differences in the shape of the semantic profiles of contact and distance lessons. Thirdly, is to establish what the semantic ranges of the two lessons reveal about their potential for knowledge building

1.6 Objectives of the study

The specific objectives of the study can be summarized as follows, given the purpose of this study:

a. To gain insight of how does cumulative knowledge-building take place in a lesson taught though distance and contact sessions.
b. To describe the similarities and differences in the semantic profiles of the distance and contact lessons.
c. To understand what the semantic ranges of the two lessons reveal about their potential for knowledge building.

1.6.1 Main research question

The study is guided by the following main research question:

How does cumulative knowledge building take place in a lesson taught though distance and contact sessions?

1.6.2 Sub-research questions

a. What are the similarities and differences in the semantic profiles of the two lessons?
b. What do the semantic ranges of the two lessons reveal about their potential for knowledge building?

1.7 Significance of the study

My study will contribute to an understanding of cumulative knowledge building in distance and contact lessons. This might influence the teaching modes that teaching and learning may rely on. An understanding of the potential of cumulative knowledge building in both distance and contact lessons will fundamentally influence how teachers may adopt new ways of teaching and learning to develop knowledge building in their teaching. Considering that the topic of semiconductors within technical sciences is relatively new in the South African curriculum, the study will add on to the limited literature about the teaching and learning of the topic. Teacher training programs may also feed from the findings of the study by preparing pre-service teachers to integrate cumulative knowledge building strategies in their teaching. As stipulated by the SACE, teachers' work lie at the heart of knowledge building, an understanding of knowledge building will generally influence and inform pedagogical strategies used by teachers in their lessons. In its broader intentions, the study will contribute to the existing knowledge as well as the limited knowledge in technical sciences.

1.8 Chapter summary

This chapter provided an introduction to the study. The problem statement, purpose of the study, and the research questions were outlined. The chapter further explained the significance of the study thereby highlighting the need for exploring this research. The bodies of literature that informed this study will be presented in chapter 2, and the conceptual and analytical toolkits for this study will be explored in chapter 3.

CHAPTER 2: LITERATURE REVIEW

2.1. Introduction

Chapter 1 provided an introduction to, and overview of the study at hand. This chapter is aimed at reviewing the bodies of literature that guided this study. The title, research questions, and sub-research questions, as well as the Legitimation code theory (LCT), which is used as conceptual framework in this study, informed the literature that the study focused on. The study looked at the following bodies of literature: the teaching and learning of semiconductors, the role of a science teacher, and importance of teachers as knowledge builders, cumulative knowledge building and affordances/constraints of distance and contact teaching.

2.2. The teaching and learning of semiconductors

In Further Education and Training (FET) phase the topic of semiconductors is only covered in Grade 10 and 12 under the theme of matter and materials. The topic of semiconductors for Grade 10 is introduced as materials whose conductivity rises with increased temperature (Rollnick, Mundalamo & Booth, 2012). In Grade 12, however, learners' study intrinsic semiconductors, doping, n-type semiconductors, p-type semiconductors, and p-n junction diodes to develop a more complex understanding of semiconductors (CAPS, 2014). A literature search revealed a few studies on semiconductors' teaching and learning.

In one of the studies conducted by García-Carmona and Criado (2009) the study examined a sequence of teaching the topic of semiconductors in a secondary school in Spain. One of the study's findings was that; for the teaching of semiconductor physics to be as successful as possible, proper coordination between science and technology teachers is needed. In addition, Wettergren (2002) conducted a study that was aimed at developing students' conceptions of semiconductor diffusion, doping and holes in the Sweden context. Furthermore, Rollnick, Mundalamo and Booth (2012) examined teachers' improvements in subject awareness as they learned to teach semiconductor topics through a self-study process. The findings revealed that content knowledge that teachers hold is closely linked with the way it is taught. Rollnick (2017) focused on understanding the role that the teacher plays in developing content knowledge as they teach the topic of semiconductors to Grade 10 learners. Both Rollnick, Mundalamo and Booth (2012) and Rollnick (2017) employed their studies in the South African context. Studies by

Garcia-Carmona and Criado (2009) and Wettegren (2002), noted that the basic concepts for the learning of semiconductors is under researched. The studies then offered some insight into possible difficulties in teaching and learning associated with semiconductors. It's worth mentioning that semiconductor teaching and learning is understudied; a research that focuses on the teaching of semiconductors would undoubtedly add to the limited knowledge. Looking at what has been done in the South African context in terms of semiconductor teaching and learning, it is evident that there is a need to broaden the scope by researching how teachers build cumulative knowledge as they teach the topic of semiconductors.

2.3. Importance of teachers as knowledge builders

Scardamalia and Bereiter (1999) made a strong case for schools to be transformed into knowledge-building institutions. Maton (2014) argues in support of this viewpoint, stating that everyone in education shares the desire to develop cumulative knowledge building. Knowledge building can be interpreted in two distinct ways. Knowledge building, according to Scardamalia and Bereiter (2003) is the development and continuous improvement of ideas of value to a society, by means that increase the possibility that what the community accomplishes will be greater than the amount of individual contributions. According to Scardamalia and Bereiter (2003), knowledge building is seen as a collaborative effort with a primary emphasis on learners as the key builders of knowledge. Tan (2010) builds on Scardamalia and Bereiter (2003)'s argument and suggests that teachers should first be knowledge builders in order to turn schools into knowledge-building organizations.

Teachers should assume the role of knowledge builders in order for learning and teaching to be effective. Maton (2014) argues that teachers must also encourage cumulative building of knowledge in order to avoid the problem of knowledge segmentation. Segmentation of knowledge occurs when pupils learn a series of discrete ideas or skills as they move through a curriculum, rather than progressively building on what they previously learned (Maton, 2010). According to Maton (2010) this segmented learning makes it difficult for students to apply their understanding to new contexts, such as later studies, everyday life or future work. Knowledge or understanding is thus locked within its contexts of production or learning. As such Maton (2014) argues that learning should expand and connects prior knowledge with knowledge generated in different contexts and at different times. This viewpoint is consistent with the professional standards of the South African Council for Education (SACE Final Draft PTs for Gazette, 2018), which argue that teachers should consider the subjects they teach as bodies of knowledge in which important concepts are connected to one another. Teachers are required to be able to plan coherent sequences of learning experiences for their learners. In addition, teachers should understand how subject knowledge can be applied to interpret and address real-world issues. Maton (2013) suggests that the business of teaching means that teachers should be able to deliver learning that expands past knowledge and connects it with knowledge produced in different contexts.

2.4. The role of a science teacher

Teachers must understand and exercise their roles in a beneficial way to help learners learn; learning is simply hindered when this task is not fulfilled. According to Blackie (2014) to build knowledge, a science teacher should explicitly make the invisible visible by shifting learners from a complex-abstract understanding to simple and concrete understandings over time. The business of science teaching in my view, is to help learners grasp the disciplinary knowledge as required by the curriculum with the help from the teacher. To support this view, the professional teaching standards (PTs) argues that teachers need to explain disciplinary knowledge to learners in ways that are understandable and accurate and teachers need to understand how subject knowledge can be applied to interpret and address real-world issues.

According to Summer (2008) the role of a science teacher is to help learners reach conceptual understanding. Byers (2019) argues that the actions that teachers take enable their learners to understand the disciplinary knowledge which further influence knowledge building. This means that science teachers should be familiar with scientific ideas, present the curriculum in a coherent way, develop learners' sense of wonder and curiosity, have knowledge of pupils' scientific capabilities, know and analyze the scientific issues that permeate contemporary life and be open to investigation and innovation practices (Naumescu, 2008). According to Summer (2008) a science teacher enhances the learning environment by making science classrooms inclusive of learners' ideas and helping learners to connect science to their daily lives. This view links directly to Blackie (2014) who argues that science teachers need to make the invisible visible so as to build knowledge. Most of the forms of literature that addresses the role of a science teacher agree to teachers producing conceptual understanding for learners. In this study, the conceptual understanding can be analyzed from an understanding of how teachers' cumulatively build knowledge in their lessons. For conceptual understanding to take place shifts in semantic codes over time play a huge role.

2.5 Cumulative knowledge building

According to Maton (2009), cumulative knowledge building is a form of learning in which new knowledge builds on and incorporates previous knowledge. Maton (2014) adds that cumulative knowledge-building expands and connects prior knowledge with knowledge generated in different contexts and at different times. Walton and Ruszynyak (2019) argue in a related manner that ideas that do not integrate existing knowledge describe the source of segmental knowledge building. For the sake of clarification, segmental knowledge building refers to learning in which new concepts or skills are acquired alongside existing knowledge rather than being built on top of it (Maton, 2009). Maton (2013) asserts that knowledge is segmented when it is so tightly bound to its context that it is only relevant within that context.

Teachers should combine ideas with stronger semantic density with ideas that has stronger semantic gravity for cumulative knowledge building to occur in teaching and learning (Walton & Rusznyak, 2019) this creates a semantic wave with a bigger range. Maton (2013) adds that cumulative knowledge-building is defined by the big semantic ranges which range from knowledge with stronger semantic gravity to knowledge with stronger semantic density. The semantic wave is crucial for both cumulative and progressive learning (Maton, 2011). The concepts of semantic waves, semantic ranges, semantic density and semantic gravity form part of the Legitimation code theory which is used as the conceptual framework in this study. In chapter 3 of the study, these concepts will be thoroughly discussed.

2.6. Affordance and constraints of distance and contact teaching/learning

Distance teaching, according to Ananga and Biney (2017), is a learning strategy in which teaching and learning are separated in time and space, with technology playing a key role in facilitating this form of delivery. Simonson, Zvacek and Smaldion (2019) contends that distance teaching can be synchronous or asynchronous. Asynchronous teaching or learning refers to live instruction facilitated by the use telecommunication systems. Examples of such modes include Zoom and Microsoft Teams. Asynchronous on the other hand refers to a situation where students can learn at different times and in different places (Simonson et al., 2019). One example of such learning involves pre-recorded lectures that are accessible from a variety of platforms for learners. Contrary to distance teaching is contact teaching which explains a common method of teaching, in which students and teachers meet in person for a specified period of time in a specific location (Buselic, 2012).

Buselic (2012) argues that distance teaching or learning is flexible as learners are able to participate and engage with the learning materials at their own convenient time. This idea clearly speaks to asynchronous learning where learners are able to access academic materials at a later stage (Simonson et al., 2019). Distance teaching does not offer immediate feedback whereas in a traditional classroom setting, learners' performance can be immediately assessed through questions and informal testing (Buselic, 2012). Additionally, with distance learning, learners have to wait for feedback until the instructor has reviewed their work and responded to it.

Although Buselic (2012) argues that feedback processes are hindered in distance teaching, scholars such Harlen and Doubler (2004); Swanson and Wheeler (2006) have indicated the merits of distance learning by focusing on the benefits of asynchronous discourse. They argue that asynchronous discourse allows learners to self-reflect on their work making learning more conducive to deep learning than the synchronous-type of discourse one would expect in a fully face-to-face setting. Brown (2019) also noted that online discussions could offer students more opportunities to think about, research and even draft their discussion answers compared to contact sessions.

On the contrary Bio (2020) argues that teaching requires significant teaching tools such as body language, facial expressions and the voice of the teacher. In distance teaching, such as online learning, these important tools as mentioned by Bao (2020), are difficult and almost impossible to use through screens as compared to contact teaching spaces. Distance teaching or learning demands a disproportionate amount of effort from the teachers (Buselic, 2012). Bao (2020) and Brown (2019) asserts that the inadequacy in experience for both teachers and learners may hinder the learning process. The aspects that the literature has revealed raises more questions on the potential for cumulative knowledge building in both these teaching modes, thus it remains vital to acquire a deep understanding on how each mode can add to the advantages of learning and teaching.

2.7. Chapter summary

In this chapter, I have given a detailed review of the bodies of literature that informed this study. I presented literature about the importance of teachers as knowledge builders, the teaching and learning of semiconductors, the role of a science teacher, affordances or constraints of distance and contact teaching as well as cumulative knowledge building. What was more alarming from the literature was that little is documented about the teaching and learning of semiconductors in the South African context. Chapter Three discusses the theoretical and conceptual underpinnings for this study.

CHAPTER 3: CONCEPTUAL FRAMEWORK

3.1 Introduction

Chapter two of the study reviewed the bodies of literature that informed this study. The aim of this chapter is to provide a detailed account of the conceptual framework that is guiding this research. According to Rocco and Plakhotnik (2009) a conceptual framework grounds the relevant knowledge bases that lay the foundations for the importance of the problem statement and the research questions. This study is informed by the specific concept of semantics from the theory of the legitimation codes (LCT).

3.2 The legitimation code theory (LCT)

Given that the study uses a specific concept of semantics drawn from the Legitimation code theory (LCT), it is important to provide a brief overview of the theory's nature. LCT is a theory that was developed by Maton (2014) on the basis of Basil Bernstein's (1971) code theory. According to Xie (2020) LCT is a sociological framework concerning knowledge practice, as Maton, Hood and Shay (2016) would put it "LCT is a practical theory of practice" (p.2). The theory attempts to explore the fields of social practice to uncover their underlying structural principles (Fagan, 2020). For this reason, LCT allows both teachers and their learners to view knowledge as the focal point of enquiry (Maton & Moore, 2010). According to Walton and Rusznyak (2019) the theory offers an approach to analyze and shape teaching practices. As such LCT provides the tools with which teachers can make the "invisible visible" by unpacking abstract concepts and linking knowledge to its particular context (Maton, 2014) or by taking complex meanings and link them with simple meanings.

LCT is made of five dimensions which are semantics, specialization, autonomy, temporality and density (Martin & Maton, 2017). Although the five dimensions of LCT may offer a way to understand cumulative knowledge building in distance and contact lessons, I chose to focus on the semantics dimension because it presents an opportunity to understand how teachers change a complex body of knowledge to accessible forms that learners can understand thereby enhancing cumulative knowledge building.

3.3 Semantics

Maton (2014) suggests that semantics view educational fields of practice as semantic structures whose guiding principles are conceived as semantic codes consisting of semantic gravity and semantic density. Together these codes and movements from stronger to weaker semantic gravity and semantic density and back again can form what LCT terms the "semantic wave", which can be used to map a teaching and learning event (Clarence, 2013). The semantic wave is the key to cumulative learning, and also to progression in learning (Maton, 2011; 2013). Given that this study seeks to understand how cumulative knowledge building takes places in social practices, the concept of semantic density and semantic gravity remain of great importance. Maton (2011) argues that semantic gravity and semantic density resolve the problems of segmental knowledge by enabling knowledge building over time during the lessons that are being taught.

3.3.1 Semantic gravity

Semantic gravity (SG) describes the degree into which teachers take abstract concepts and bring them closer to learner's everyday lives or real –world situations (Walton & Rusznyak, 2019). It can be relatively stronger (+) or weaker (–) with infinite variations (Maton, 2014). The stronger the semantic gravity (SG+), the more meaning is dependent on context; the weaker the semantic gravity (SG–), the less meaning is dependent on context (Botyczoko, 2020). According to Clarence (2013), when teaching and learning leans too much towards weaker or stronger semantic gravity to the exclusion of the other, the potential to accumulate knowledge and transfer it between and through contexts is impeded. In other words, if learning is too abstract or too context-dependent, students will fail to apply the knowledge differently in different contexts (Clarence, 2013).

For example, if we look at the topic of semiconductors, aspects such as band gap; that is a set of prohibited energies within the materials' electronic structure is an abstract concept. When a teacher uses concrete examples or everyday examples to teach this concept, the examples have a stronger semantic gravity because the ability to express meaning within that context would be understood. Walton and Rusznyak (2019) states that when learning is generalized and transferred to different contexts then the semantic gravity becomes weakened. In this study, semantic gravity was categorized into four strengths: SG+++, SG++, SG+ and SG−. The strongest semantic gravity is represented by SG+++, while the weakest is represented by SG−.

3.3.2 Semantic density

Semantic density (SD) "refers to the degree of condensation of meaning within practices" (Maton, 2014b, p. 129). Semantic density is stronger (SD+) when meanings are condensed and semantic density is weaker (SD−) when meanings are less condensed (Fagan, 2020). In simple terms the concept of semantic density describes the degree into which teachers change knowledge from complex to more simple forms that learners can understand (Walton & Rusznyak, 2019). Maton and Doran (2017) comment that to make the semantic density weaker a complex concept should be simplified and made more understandable by using common words. Stronger semantic density (SD+) on the other hand means that there is more complexity in a word or phrase (Cranwell & Whiteside, 2020).

For an example on the topic of semiconductors, the concept of doping is condensed and requires subject specialists' knowledge to understand. When working conceptually with their learners, teachers are consistently building the semantic density. Hugo (2014) argues that complex concepts must be broken down into their specific elements and once understood, they must be incorporated with other concepts to explain a higher process. Hugo (2014) adds that when a teacher "unpacks" a concept, semantic density weakens; but, when she "packs" the concept up and uses it as a whole to understand complex ideas, semantic density increases.

The more meanings are related, the stronger the SD. Similar to semantic gravity, semantic density strength also varies along a continuum of strengths (Maton, 2011). In this study semantic density was categorized into four strengths: SD+++, SD++, SD+ and SD−. The strongest semantic density is represented by SD+++ and the weakest with SD− . The associated meanings of these codes are explained in detail in chapter 4 of the study.

Semantic density and semantic gravity are independent of each other. For instance, if a concept is abstract or requires learners to connect two or three theories (SG−), but the terminology used to explain it is not complex (SD−), the classification would be (SG−, SD−) (Cranwell &

Whiteside, 2020). This description is provided so as to allow the reader to understand the relationship between SD and SG as shown in the diagram below.

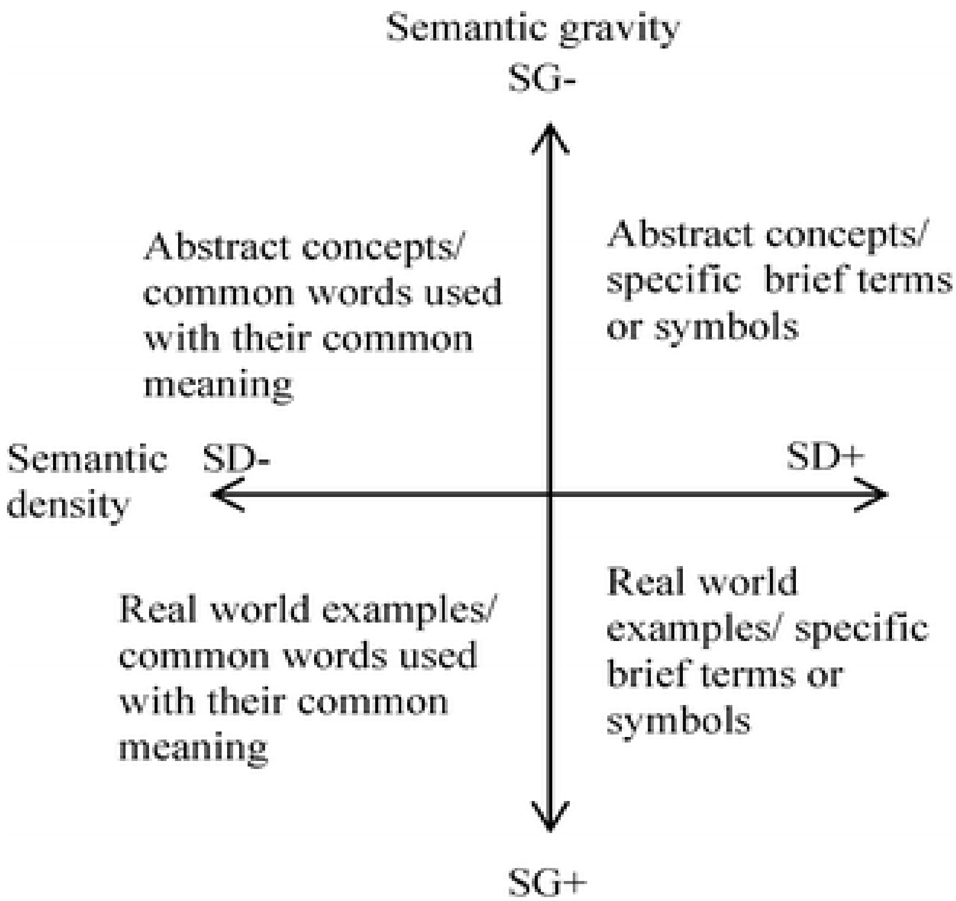


Figure 1. Shows the relationship between semantic density and semantic gravity (Maton, 2011)

In the upper left quadrant, we are looking at meanings that are abstract and context dependent (weak semantic gravity and weak semantic density). In the upper right quadrant, we are looking at meanings that have weak semantic gravity and strong semantic density. In the lower left quadrant, we are looking at strong semantic gravity and weak semantic density. Finally, in the lower right quadrant we are looking at stronger semantic density and stronger semantic gravity. Cumulative knowledge does not reside in any one of the quadrants however teaching waves between the quadrants to form a semantic wave.

3.3.3. Semantic profile, semantic waves and semantic ranges

The continuous movement between semantic gravity and semantic density over time can be represented as a semantic profile, which is a useful tool for visualizing how knowledge practices work in knowledge building (Xie, 2020). As we will see, the analyses of the videos in this study may demonstrate various semantic profiles that show how practices shift in terms of context dependence. Maton (2013) defines a semantic scale as the range between the highest and lowest strengths of SD and SG. Maton (2014) states that semantic profiles are important for analyzing cumulative knowledge building. The diagram below shows the semantic scale (range of SD and SG)

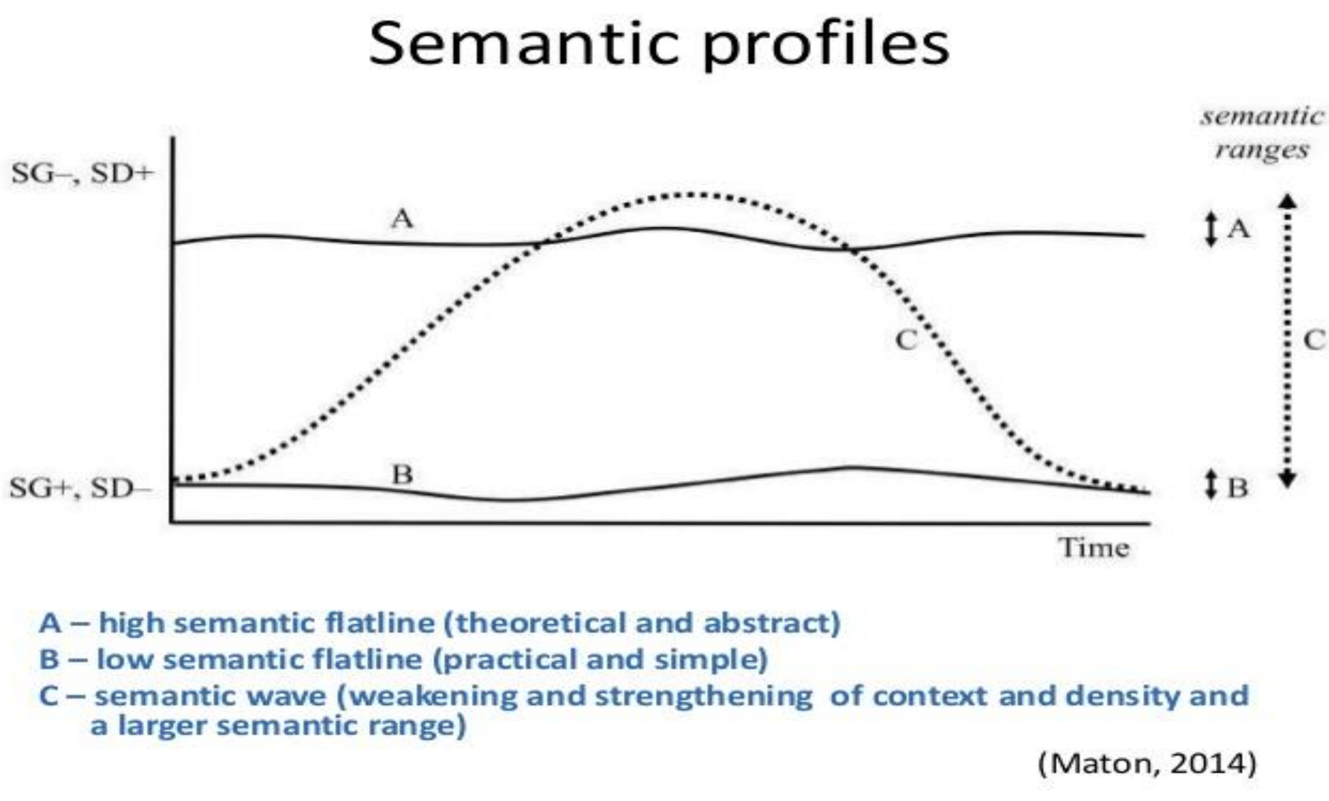


Figure 2. Shows a semantic profile adapted from Maton (2014)

The above profile reveals how knowledge is built over time. A high semantic flat-line shows that concepts remain unpacked and complex for learners to understand, a low semantic flat-line shows that learning of a concept is too simple (Walton & Rusznyak, 2019), when teaching occurs in the form of semantic flat lines no learning occurs. Maton (2013) states that semantic waves represent the pulse of cumulative knowledge building that involve the shifts in context-dependent, simplified meanings and decontextualized, condensed meanings. The business of teaching means that we should create waves. In simple terms, semantic waves refer to the upward and downward shifts in semantic profiles that characterize classroom practice (Msusa, 2019). According to Msusa (2019) a semantic wave may be characterized by a downward movement on one end, which is essentially the “unpacking” of technical terms, concepts or definitions into more familiar common-sense language for learners. This can also be described as movement from context-independent symbols whose meanings are relatively abstract. On the other end the inverse upward movement is a “repacking” process, where engagement with the knowledge is now grappled with using terms and concepts as well as application of theories in own voice. In other words, grappling with context dependent material that has quite specific meanings. As Maton (2013) discusses, the concept of semantic waves can be used in a variety of ways as a tool to trace changes in knowledge through time.

There are instances were knowledge may be too closely linked to particular contexts and too fragmented to build on prior knowledge either. According to Maton (2013) such practices describe high stakes profiles which are characterized by knowledge that is segmented. Maton (2013) further argues that high stakes profiles present potential problems for the building of cumulative knowledge, since knowledge is characterized by relatively strong semantic gravity and relatively weak semantic density.

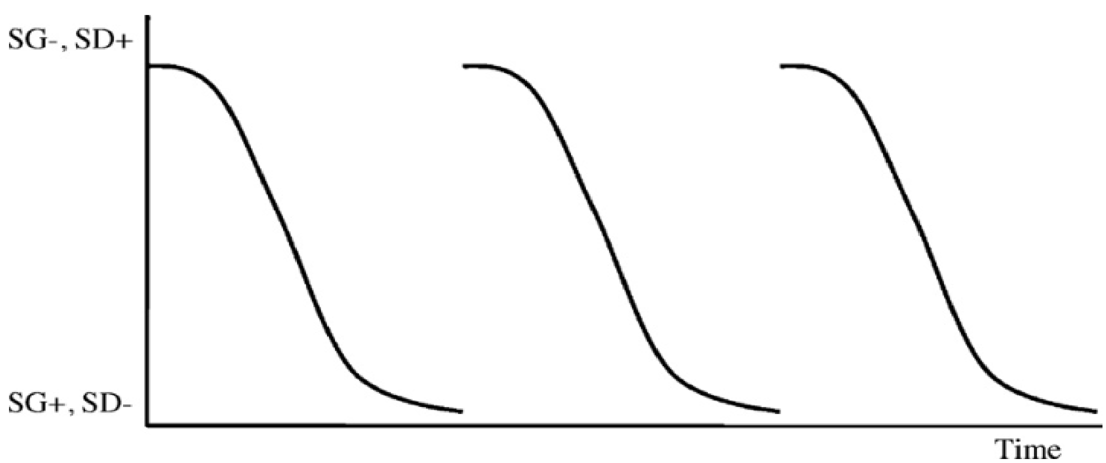


Figure 3. Shows an example of a high-stake profile (down escalators) (Maton, 2013)

3.4. Translational device

Cowley- Haselden (2020) argues that the translation device provides constant interactivity between theory and data allowing direct paths between the two. In this study, the translational device was used to facilitate the mapping in strengths of semantic gravity and density in both distance and contact lessons. The theory of legitimation codes provides the thick description through the use of the translational device. Chapter 4 provides a detailed outline of the adapted translation device used in this study.

3.5. Chapter summary

This chapter outlined the conceptual framework employed in this study. The key concepts of semantic density, semantic gravity, semantic ranges, semantic profiles and semantic waves have been discussed showing their relevance for this study. This overview provides the lens with which my research questions posed in chapter one are to be answered. The chapter offered general insights on the translation device that was adapted for the study. In chapter four, I will give an introduction to the research methodology where details to the methodological and analytical approaches that this study used will be looked at.

CHAPTER 4: RESEARCH METHODOLOGY

4.1 Introduction

Chapter two and three of the study introduced the reader to the literature and the conceptual toolkits that guided the study. For the purposes of drawing the theory of LCT into the methodological and analytical approaches this study has adopted- I will show how the theory of LCT encompasses the research methods that are deployed in this study. LCT has been chosen as the central conceptual and analytical framework and applied to this study not only because of the rigor that the conceptual framework enables in research and depth of its “explanatory power” (Maton, 2013a), but also because of its relevance as an analytical and organizing framework for organizing, exploring and analyzing data (Clarence, 2013).The aim of this chapter is thus to present the research paradigm, research approach , research design, data collection methods and data analysis tools that will be selected to facilitate in the process of addressing the study’s objectives.

4.2 Restating the objectives of the study

The primary objective of the study is to gain insight of how cumulative knowledge-building takes place in a lesson taught though distance and contact sessions. The literature review section pointed out that distance sessions are described as learning and teaching that assumes that the teacher and learners are apart in space and that this distance is bridged by the use of technological tools (Ananga & Biney, 2017). Contact sessions are seen as a more common method of teaching, in which learners and instructors meet in person for a specified period in a specific location. The secondary objectives of the study are: to describe the similarities and differences in the semantic profiles of the distance and contact lessons and to understand what the semantic ranges of the two lessons reveal about their potential for knowledge building. The following section discusses the research design before the chapter moves on to describe the data that was gathered.

4.3 Research paradigm

Hatch (2002) argues that every research is guided by a paradigm. A paradigm is a knowledge base characterized by a collection of beliefs or theories about "how the world is organized, what we really know about it, and how we may know it" (Hatch, 2002, p.11). The study's epistemological and ontological position is determined by the research paradigm, so it's critical to find one that reveals the researcher's philosophical and ontological perspectives on what they are researching about (Zulu, 2018). This study is underpinned by the social realism paradigm due to the use of the theory of LCT as the lenses for analyzing the data. According to Maton and Moore (2010) LCT is a major conceptual paradigm in social realism, viewed as a broad "school of thought" that aims to go beyond social constructionism.

Not only does social realism demonstrate that knowledge is socially constructed, dynamic, and the subject of ongoing struggles among historically and socially situated actors with varying resources, but it also demonstrates how knowledge's various forms have their own properties, strengths, and tendencies, which help shape ongoing struggles (Maton & Howard, 2011). The aim of social realism is to see beyond the surface to the actual systems that lie underneath them, while still acknowledging that these structures are more than just a function of social control and beneficial interests (Maton & Moore, 2010). Drawing from this statement it remains clear that knowledge extends from the social aspect as it is also regarded as real. As argued by Maton and Howard (2011) some kinds of knowledge are ideally suited to the learning needs of some social groups than others, and some are better suited to cumulative knowledge-building than others.

4.4 Research approach

In educational research, there are three major types of research approaches: qualitative, quantitative, and mixed methods approaches (Creswell, 2012; McMillan, 2012). Qualitative research approach is concerned with providing a naturalistic observation that translates into a detailed description of the phenomenon under study while quantitative research is concerned with measuring and testing general laws (Auerbach & Silverstein, 2003). Mixed method approach is a unique approach as it works with both qualitative and quantitative approaches (Creswell, 2012). In this study a qualitative approach within the social realism paradigm was appropriate since I was not concerned with measuring any variable. Qualitative research is a "systematic scientific inquiry which seeks to build a holistic, largely narrative description to inform the researchers' understanding of a social phenomenon" (Astalin, 2013, p. 118). Given that the study seeks to "gain insight", "to understand" and "to describe" a phenomenon the qualitative approach thus provides an in depth understanding of how people manage their day to day situations. In this study the aim was to understand cumulative knowledge building occurring in a social context thus, using the qualitative approach will not only provide insights into how cumulative knowledge building occurs in contact and distance lessons but will further give a descriptive and interpretative view of the overall study.

4.5 Case study research design

In education research, case studies are typically conducted on a small scale with clearly defined boundaries. Case studies are often searching for particular items in a specific location and are known for their in-depth and extensive analysis (Cohen, Manion & Morrison 2007). In addition, case studies are descriptive and explanatory and they allow for a qualitative detail. The research questions in this study includes the "*what*" and the "*how*", thus case studies may be used to explain casual links between the data the questions (Babbie & Mouton, 2010). In this study two cases of teachers teaching a topic of semiconductors in technical sciences for Grade 12 learners were studied. In one case, the teacher taught the topic using distance modes while in another, the teacher taught the topic in a contact session, where interaction physically occurred between the teacher and the learners. The two cases were then studied collectively so as to understand how cumulative knowledge building take place in an in-depth manner. Yin (2003) states that collective case studies provide a description to multiple case studies. For the purposes of this research two cases were chosen so that I am able to compare the similarities and differences of the semantic waves and the ranges in these two modes of teaching. Although case studies provide an in-depth analysis of a particular context, it remains notable that the findings of this study cannot be generalized to all Grade 12 technical science teachers as a population.

4.6 Data collection methods

Data collection methods are tools used by researchers to gather information about the specific subject under scrutiny (Babbie & Mouton, 2007). Pre-recorded video observations were used as the primary source of data in this research, with document analysis serving as a complement to help me understand the depth of subject matter knowledge that the teachers should present to the learners.

4.6.1 Pre-recorded video observations

Pre-recorded video observations are a form of research observations were the researcher uses videos that are already recorded to understand an event that has already taken place. Observations enable the researcher to use the five senses to describe existing situations, resulting in a written and clear image of the situation under study (Erlandson, Harris, Skipper & Allen, 1993). Two videos were used in this study. One included the contact session teaching while the other included the distance session teaching. Distance teaching can take many forms, including live sessions in the form of Zoom Meetings, Microsoft Teams and even WhatsApp, however, the distance lesson used in this study included a scenario in which the teacher records the lesson and then uploads it for students to watch. To collect data for the contact lesson, pre-recorded videos seemed appropriate considering the global pandemic which has restricted face to face interactions with the participants and thus preventing direct observations. On the other hand, the distance lesson made use of a video which was downloaded from the mindset online platform. Both videos were one hour long.

Although pre-recorded observations allowed me gain insight of how cumulative knowledge building takes place in both contact and distance lessons, the issue of ethical considerations remained a concern. For an example, the question of identifying or not identifying the participants in the research’s final reporting. In this study, this issue was mitigated by the use of pseudonyms and making the images of the teachers and learners blurry to maintain anonymity.

4.6.2 Document analysis

According to Bowen (2009) document analysis is a tool for systematically studying and assessing written and digital documents. One of the advantages for using document analysis as a data collection method is that the research process has no impact on the documents because they are unobtrusive and non-reactive (Bowen, 2009). Document analysis was used because it involves the study and interpretation of data in order to gain significance, understanding and empirical knowledge. For the purposes of this study, document analysis seemed efficient as it was less time consuming since it involved the selection of data rather than the intensive collection of data. The documents that were analyzed for this study included the National Curriculum and Assessment Policy Statement (CAPS) for Grade 10-12 technical sciences, technical science Grade 12 teachers' guide and technical science Grade 12 learners' book which are CAPS compliant. Firstly, the analysis of these documents was aimed at noticing the depth of the content knowledge that the teachers should be providing to the learners as required by the Grade 12 curriculum. Secondly, the aim was to gain insight of how content is presented through these documents. Understanding how content is presented, allows for an understanding of the enactment of the content during the teaching and learning processes. The picture below shows an example of the selected data that was relevant for this study.

Matter and Materials			
Time	**Topic Grade 12**	**Content , Concepts & Skills**	**Guidelines for Teachers**
4 hrs	Electronic Properties of Matter	• A semiconductor is a material which has electrical conductivity between that of a conductor and an insulator such as glass.	
	Semiconductor	• Explain semiconductor with an example. (No energy band theory).	
	Intrinsic Semiconductor	• An intrinsic semiconductor is a pure semiconductor.	
	Doping	• Doping is the process of adding impurities to intrinsic semiconductors.	
	n-type semiconductor	• Discuss n-type semiconductor.	
	p type semiconductor	• Discuss p-type semiconductor.	
	p-n junction diode	• Discuss the construction and working of a p-n-junction diode.	
	Experiment 5	• Study the characteristics of p-n junction diode. (Materials: Semiconductor diode, Voltmeter, milliammeter, Rheostat, switch, battery connecting wires etc.)	

Figure 4. Shows an image taken from the National Curriculum and Assessment Policy Statement (CAPS) for grade 10-12 Technical Sciences.

4.7 Rigor: Validity and Reliability

According to Patton (2002), validity and reliability are two aspects that any qualitative researcher should consider when planning a study, analyzing data, and evaluating the study's quality. Researchers need to be concerned with answering the following question: What can a researcher do to persuade his or her audience that the study findings are meaningful? (Lincoln & Guba, 1985, as cited in Golafshani, 2003). As argued by Brigitte (2017) without rigor, research is meaningless, becomes a fiction, and loses its sense and validity. According to Brigitte (2017), rigor is the quality or state of being extremely precise, thorough, rigid, and highly accurate.

4.7.1 Validity

Validity is an important criterion in both quantitative and qualitative research since it is a significant aspect of research (Nyamupangedengu, 2015). This is due to the fact that if a part of the study is deemed invalid, it is rendered useless (Cohen, Manion & Morrison 2007). It is necessary thus to ensure that one reports on findings that are valid. This means that my findings need to reflect truthfully what I had gained from the data collection instruments. In my study, I used a variety of platforms available at the University of Witwatersrand to address the issue of validity. The details of the platforms are described in detail below.

Virtual Research Bonanza: The Wits School of Education usually conducts research Bonanzas each year. During the proposal stage of my research I presented my work where I received intensive and useful feedback from the Wits research community. One of the recommendations I received from the research group was to use at least two types of data collection methods to verify my findings. I then used document analysis as a means of data collection to complement the pre-recorded video observations in my research design.

Writing retreats: In 2020 I attended two writing retreat seminars where I presented my proposal and received intensive feedback that was very useful. I then attended two writing retreat seminars in 2021 where I presented my preliminary data analysis and findings. During the writing retreats I was assigned to mentors who are senior researchers in the faculty to read and provide feedback on my work.

LCT@Wits Knowledge Building Research Team: In addition to presenting my work at the research bonanza and the writing retreats, I worked closely with the Legitimation code theory (LCT) senior researchers and students where I presented my data analysis and findings. I got a lot of input in these sessions, it was suggested that the semantic waves graphs that the lessons produce should also show a situation where the teacher introduces a new concept within the broader topic. The feedback which I acquired helped me validate my findings. Additionally, my data was independently analyzed by an LCT scholar.

4.7.2 Reliability

The evaluation of trustworthiness is critical in qualitative research to ensure reliability (Golafshani, 2003). Guba and Lincoln (1989, as cited in Maher, Hadfield, Hutchings & de Etyo, 2018), recommend that the study should meet the following conditions to ensure that the process is trustworthy: credibility, transferability, dependability, and confirmability. My research studied what was expected and offered a true representation of the participants' social reality in order to gain credibility (Maher et al., 2018). The possibility of the findings to be applied to other contexts or environments is referred to as transferability. Transferability was possible in this study due to the use of the translational device (specific details given in tables in 4.9.1 and 4.9.2) which can be tailored or adapted and used by other researchers. Since my study is qualitative and limited to a specific case, it is important that a detailed explanation be given so that the reader can determine if it is transferable to their context (Maher et al., 2018).

The main criticism of qualitative research is that it is often not generalizable. However, transferability can be achieved through providing a thick description of the phenomena (Mackey & Gass, 2005, as cited in Cowley-Haselden, 2020). The theory of legitimation codes provides a thick description through the use of the translational device. The *specific translation device* used in this study enables me to identify strengths of semantic gravity and semantic density in my data (Maton & Doran 2017). Cowley- Haselden (2020) adds that the translation device provides constant interactivity between theory and data by allowing direct paths between the two. To achieve dependability, the processes used in the study are adequately explained so that another researcher can repeat the same work. Finally, in order to adhere to confirmability in this study, I prevented bias through allowing one of the LCT scholars to analyze the data independently. In addition, I reviewed my findings with the LCT research team.

4.8. Data analysis

Creswell (2009, as cited in Nkambule & Murekedzi, 2017) states that the analysis process involves creating sense from the data, preparing data for analysis and moving further and further into the comprehension of the data. In analyzing my data, I used the semantics dimension of the legitimation code theory as the lens for interpreting the data. The methods and actions that were taken in this study included listening to the videos many times and re-reading the documents to get meaning of the data produced. Pre-recorded videos were used to observe how cumulative knowledge building takes place in contact and distance lessons while documents were analyzed to gain insight of how content in technical sciences for Grade 12 is presented. The analysis of the pre-recorded videos and documents occurred in three stages.

Stage 1: The pre-recorded videos were watched multiple times in preparation for the process of transcription. In the process of transcription, I created a table that specified what was happening in each lesson at any given point in time and the associated codes. Below is an example taken from the contact lesson transcription showing how the table was set out.

Time in the lesson	**Description of what was happening in the lesson**	**Coding (SG and SD)**
	Teacher: Remember previously when we were dealing with semiconductors. The last lesson was about the extrinsic semiconductor when we introduced doping as a method of increasing conductivity in semiconductors. Can you tell me exactly what is doping from the previous lesson? What did I say about doping? Yes? *Pointing to the learners.* Refilwe: Conductors that ……*inaudible*	SG− (Theoretical statement) SD+ (Teacher uses technical/subject terms, and explains what it means in an understandable way)

Figure 5. Shows an example of the layout of the table in preparation for transcription for the contact lesson

Stage 2: Familiarization with the transcribed data occurred. In this stage I created a table of the associated semantic gravity and semantic density codes in preparation for coding. The videos were replayed and documents were further scrutinized to ensure that I do not miss any significant aspects. The figure below shows the identification of the codes and their associated meanings. This process enabled me to be consistent in my semantic code assignment while allowing the reader to understand how and why I assigned the semantic codes the way I did. The semantic codes and their specific meanings are described in the following tables below. Semantic gravity, abbreviated as SG, describes how context-bound or abstract meaning is, while semantic density, abbreviated as SD, explains how simple or complex meaning is.

Weaker → Stronger	Code	Indicator
	SG−	Teacher explains a theoretical statement.
	SG+	Teacher refers to a hypothetical example.
	SG++	Teacher focuses on the real-world example / direct experience.
	SG+++	Teacher focuses on personal experiences / examples.

Table 1. Shows the semantic gravity codes and their specific meanings

Stronger ↑ Weaker	Code	Indicator
	SD+++	Teacher uses condensed symbolic language to convey a concept.
	SD++	Teacher makes connections between the concept and other ideas so that it becomes part of a networked body of knowledge.
	SD+	Teacher uses subject terms, and explains what it means in an understandable way, giving more details about the characteristics and properties of the concept.
	SD−	Concepts or words from the subject are used to convey meaning in straightforward ways that a non- subject specialist could understand.

Table 2. Shows the semantic density codes and their specific meanings

Stage 3: In the final stage, parts of the lesson transcriptions were assigned varying semantic codes which depended on the indicators that are shown above. For an example when the teacher explained a theoretical statement a code of SG− was assigned and when the teacher used condensed symbolic language a code of SD+++ was assigned. The table below shows an example of a coded transcript taken from the distance lesson. Both lessons were analyzed in a similar way.

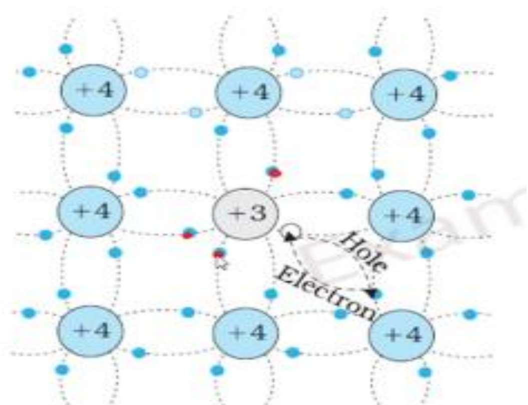
Let us now discuss p-type semiconductor, so once we have discussed the n-type semiconductor it is easy to understand p-type semiconductor. In p-type semiconductor we have group 3 impurity, so a group 3 element would be a trivalent element as it will have the valence of 3 electrons.	Teacher introduces a new concept SG− (Theoretical statement). SD+ (Teacher uses subject terms, and explains what it means in an understandable way).
Let us take the example of a Group 3 elements aluminum (Al). What would be the electronic configuration of Al? It will be$1S^2 2S^2 2P^6 3S^2 3P^1$. So that means in the outer shell which is shell corresponding to n = 3 we have how many valence electrons? We have 3 valence electrons. So, what happens in this case, this is my Al impurity, so it has got 1, 2 and 3 valence electrons **(making dots on the diagram as shown below).**  	SG+ (Hypothetical example) SD+++ (Teacher uses condensed symbolic language to convey a concept)

Table 3. Shows an excerpt of a coded lesson transcription.

4.9 Translation device

After completing all of the stages, I created a complete translation device that included examples from the lesson transcriptions. The translation device was adapted from Maton (2014) and tailored to suit the specific requirements for this study. The tables below describe the translation devices for semantic gravity and density.

4.9.1 Translation device for semantic gravity

Semantic gravity (SG) – how context-bound or abstract the meaning is

Code	**Indicator**	**Examples from the analyzed lesson transcriptions**
SG−	Teacher explains a theoretical statement	So, conductivity is inversely proportional to resistivity, if the resistance is high the conduction will be low. Because resistance is nothing but the barrier to conduction. So, if conductors have high conductivity it is quite obvious that they have low resistivity. Insulators will have on the other hand, very high resistivity and semiconductors will have intermediate resistivity as well.
SG+	Teacher refers to a hypothetical example	You include-we actually bring in the foreign element. You still remember the alien element? Silicon crystals if you still remember. So, we had some silicon crystal with electrons around it and we introduced a certain element which element can you remember? There was an alien- a foreign element that we used.
SG++	Teacher focus on real world example/direct experience	Objects which you see around yourself, all objects like your laptop, your computer, a transistor, your microwave, your refrigerator, your cameras, video recorders, your calculators, batteries. There are so many things which you see around yourself and all of these have application of semiconductors.
SG+++	Teacher focus on personal experiences/examples	The practical experiment conducted by learners.

Table 4. Describes the translation device for semantic gravity

4.9.2 Translation device for semantic density

Semantic density (SD) – how simple or complex the meaning is

Code	**Indicator**	**Examples from the analyzed lesson transcriptions**
SD+++	Teacher uses condensed symbolic language to convey a concept.	The symbol of an anode is A. The negative is sometimes called a cathode; a symbol of a cathode is K. Earlier what was the barrier height? It was V_0 now it will become $V_0 - V$ so it will be reduced by V.
SD++	Teacher makes connections between the concept and other ideas so that it becomes part of a networked body of knowledge.	So now we have two possibilities, if we dope it with the group 5 impurity - that extrinsic semiconductor is known as n-type semiconductor. And if we dope it with the Group 3 impurity it is known as a p-type semiconductor.
SD+	Teacher uses subject terms, and explains what it means in an understandable way, giving more details about the characteristics and properties of the concept.	Semiconductors as the name suggests is something between conductor and insulator. Semi means partially – half conductor, half insulator. So, when I compare the semiconductor with conductors and insulators, what do we see? Conductors will have got high conductivity and insulators have low conductivity, but when I talk about semiconductors, they have intermediate conductivity. That means their conductivity is less than that of conductors but greater than that of insulators.
SD−	Concepts or words from the subject are used to convey meaning in straightforward ways that a non-subject specialist could understand.	Now it's more like a p and n are now together, they are now combined that is why we call it a p-n junction.

Table 5. Describes the translation device for semantic density

4.10 Ethical considerations

Ethical clearance to conduct research at the Wits School of Education was granted. Consent to use the pre-recorded videos for contact lessons was granted from the previous study which the teachers participated in. However, to adhere to the issues of informed consent, letters of consent were addressed to the teachers who were teaching in the contact session so that they allow me to use their videos in my study. It was imperative that the teachers agree to be participants in my study as the nature of the study is different from that which they gave consent to. To maintain anonymity and confidentiality, the participants in the videos (both contact and distance sessions) were given pseudo names and their faces were blurred to ensure that they are not identifiable. Furthermore, there was no need for consent with the distance lesson teacher since the pre-recorded video was publicly accessible.

4.11 Chapter summary

This chapter included a detailed description of the research design that was used to carry out this study. To recap, the study was informed by the social realism paradigm, which was used in accordance with a qualitative research approach. The primary data collection method was pre-recorded video observations of the contact and distance lessons, with document analysis operating as a supplement. Reliability and validity issues were discussed and addressed in a broad sense. This chapter also went into the specifics of how the data was analyzed and the stages that were involved in the process. The choices made for each research process were reviewed and justified, and the study's ethical adherence was outlined.

CHAPTER 5: PRESENTATION OF FINDINGS AND DISCUSSIONS

5.1. Introduction

The first chapter provided an overview of the introduction for the study, while chapter two provided a detailed overview of the bodies of literature that informed this study. Chapter three focused on the conceptual framework, which provided the lens through which my research questions posed in chapter one were to be answered, finally chapter four provided the specifics of how the collected data was analyzed. This particular chapter focuses on presenting the findings of the study. The chapter begins by presenting findings that address the main research question which seeks to understand how cumulative knowledge building take place in lessons taught through distance and contact sessions. In order to address the findings for the main research question adequately, I will start by presenting detailed findings relating to the distance lesson followed by the contact lesson. The chapter will also address findings that speak to the similarities and differences in the semantic profiles of the two lessons. Additionally, I will focus on what the semantic ranges of the two lessons reveal about their potential for knowledge building. Finally, a brief segment about how both lessons develop learners as science knowers will be examined. The analyzed data was to answer the following main and sub-research questions:

Main research question:
How does cumulative knowledge building take place in a lesson taught though distance and contact sessions?

Sub-research questions:

a. What are the similarities and differences in the semantic profiles of the two lessons?
b. What do the semantic ranges of the two lessons reveal about their potential for knowledge building?

5.2. Brief summary of the key concepts

To recap briefly, the concepts of semantic gravity, density and waves provides an analytic tool for understanding underlying knowledge structures and changes within a teaching practice (Maton, 2014). The degree to which teachers bring abstract concepts closer to learners' everyday lives or real-world situations is referred to as semantic gravity (Walton & Rusznyak, 2019). Simply put, semantic gravity is concerned with the degree to which meanings are linked to their context. The stronger the semantic gravity (SG+++), the more context-dependent meaning is; the weaker the semantic gravity (SG−), the less context-dependent meaning is (Maton, 2013). On the other hand, semantic density refers to the degree to which meaning is condensed within practices (Maton, 2014). Stronger semantic density (SD+++) means more meanings are condensed within a concept, while weaker semantic density (SD−) means less meanings are condensed within a concept (Clarence, 2013).

Since I will refer to the concepts of strengthening and weakening semantic gravity and density in this chapter, it is necessary to provide a quick overview of the concepts so that the reader can follow along with the findings and interpretations. Weakening semantic gravity (SG↓), describes a situation in which a teacher moves away from the specific details of a case towards generalizations and abstractions while strengthening gravity (SG↑), defines a movement from generalized or abstract ideas towards concrete and delimited cases (Martin, Maton & Doran, 2020). Weakening semantic density (SD↓), refers to the movement from a highly condensed symbol to one with fewer meanings, while strengthening semantic density (SD↑), refers to the movement from a word, symbol, or practice with a limited number of meanings to one with a greater range of meanings (Martin et al., 2020). The continuous shifts of semantic gravity and semantic density over time during the lesson can be represented in a semantic profile. Semantic profiles are essential for understanding and analyzing cumulative knowledge building (Maton, 2014).

5.3. Findings on how cumulative knowledge building takes place in a lesson taught through distance and contact sessions.

To provide a simple overview of findings for this question, I will start by looking at the shifts in semantic gravity and density for the distance lesson, then move on to the shifts in semantic gravity and density for the contact lesson as the chapter progresses.

5.3.1. Shifts in semantic gravity (SG) over time in a distance lesson

As the lesson begins, the teacher introduces the concept of semiconductors using an example which focuses on the real-world knowledge and direct experiences that learners are quite familiar with. The teacher starts the lesson by saying:

Objects which you see around yourself, all objects like your laptop, your computer, a transistor, your microwave, your refrigerator, your cameras, video recorders, your calculators and batteries. There are so many things which you see around yourself and all of these have application of semiconductors.

The teacher uses a visual representation in the form of a picture to anchor the above statement so as to bring to life the objects she has mentioned.

Image 1. Visual representation of direct examples

This situation has a stronger degree of semantic gravity, as indicated by the code (SG++) (See the semantic profile below at time interval 0-10 minutes). By doing so, the teacher is able to use a direct example to bring meaning closer to the learners' daily lives. The teacher then repacks the concept of semiconductors and moves along an SG+ continuum, presenting a hypothetical example. By moving from a direct experience (SG++) to a hypothetical or imaginary example (SG+), the teacher weakens the semantic gravity slightly.

Teacher: *Try work something like this, if you look at any circuit, for an example if you try to open the CP of your computer, what do you see inside? So many circuits, right? It's like a small board with so many resistors, capacitors, inductors, all these things. Behind this you also get to see certain things like diodes.*

The teachers' presentation of knowledge does not end at SG+; instead, she approaches a maximum point in the graph when she introduces a theoretical statement, which is denoted by SG− in the semantic profile below. Using examples from university professional education and English secondary school, Maton (2009) examined whether cumulative learning was enabled or not. In his conclusions, he noted that SG must be weakened (knowledge must be less context-dependent) for cumulative learning to occur. This assertion is based on the assumption that when students' comprehension is grounded in context, learning is hindered, resulting in segmented learning (Hassan, 2017). The teacher moves from context-bound meanings to abstract disciplinary knowledge, widening the scope of cumulative knowledge building. She says:

So now let us quickly talk about how semiconductors came into picture. People were always more interested to make use of controlled flow of electrons. Flow of electrons constitutes nothing but electric current.

One of the most important aspects to note is that the teacher does not end at the theoretical level of SG−, but rather strengthens the semantic gravity through the process of unpacking, as shown by the comment below. Unpacking is denoted by a downward curve that strengthens the semantic gravity. See extract below.

Teacher: *So, the semi-solid-state semiconductor gradually replaced the valves. The television is a good example because all of you have seen how these LCD televisions took over the old television sets. Referring to the diagram below.*

Image 2. Shows an example of a hypothetical example

In this lesson, it is easy to analyze the semantic gravity continuum in terms of weakening and strengthening. The semantic profile below depicts a continuous wave in which semantic gravity weakens and strengthens over time in a lesson. When the teacher moves from specific cases to abstractions and back again, she weakens and strengthens semantic gravity over time. The repeated weakening and strengthening of semantic gravity describe a semantic gravity wave which is a key feature of cumulative knowledge building (Maton, 2014).

Semantic profile showing shifts in semantic gravity – distance lesson

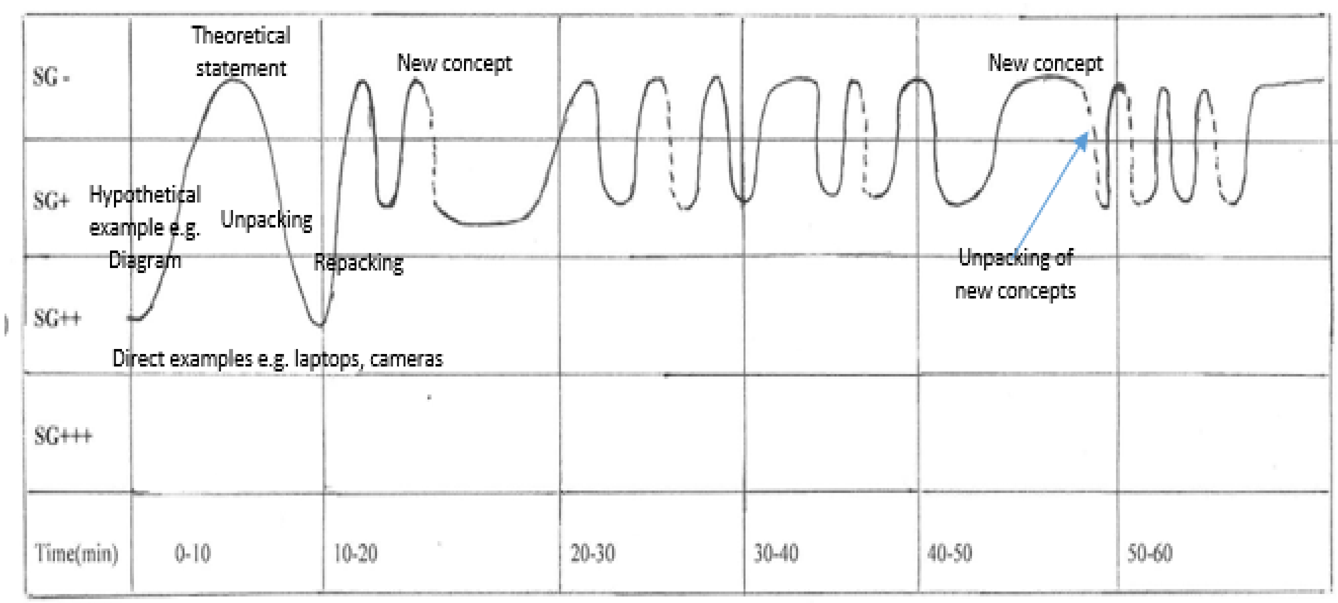


Figure 6. Shows shifts in semantic gravity of a distance lesson over time

According to the Grade 12 CAPS document for technical sciences, learners study a few complex sub-concepts on the topic of semiconductors. For an example the concept of intrinsic semiconductors, doping, n-type semiconductors, p-type semiconductors, and p-n junction diodes are amongst the mentioned few. During the lesson, the distance lesson teacher, introduces some of these concepts. One of the most significant findings was that new concepts were introduced at an abstract or theoretical level of SG−, which indicates a weaker semantic gravity, followed by a series of unpacking through the use of hypothetical examples, which represents a slightly stronger semantic gravity, denoted by SG+. According to Singh, Hugo, and Essack (2013), unpacking can be visualized as a downward curve that indicates a shift from decontextualized meanings to the use of common examples. I will use extracts from the lesson transcription as examples to highlight this point. One example depicts a situation in which the teacher spends a considerable amount of time at SG+ after introducing a new concept (10-20 minutes interval from the semantic profile), whereas the other describes a scenario in which the teacher spends more time at SG−(40-50 minutes interval from the semantic profile).

The teacher introduced the new concept of extrinsic semiconductor to the learners at a time interval of ten to twenty minutes.

Teacher: *Extrinsic semiconductor will be something which is impure. In extrinsic semiconductor, small amount of a suitable impurity was added to it. What was the purpose of adding this impurity? So that it can conduct without supplying some external energy that sounds interesting right?*

Since meaning is not bound to any specific context, the preceding statement is an example of weakened semantic gravity (SG−) (Maton, 2011). The statement is purely theoretical and abstract and the teacher spends a considerable amount of time theoretically illustrating the concept. The teacher does not end at SG− but manages to incorporate hypothetical examples, which strengthens the semantic gravity explaining a situation of concept unpacking. As seen in the semantic profile above, the teacher then spends a significant amount of time at SG+, where she builds the concept using a variety of hypothetical examples before repackaging and returning to the theoretical understandings. The upward curves represent a transition from a real-world example to abstractions, highlighting the process of repacking (Singh et al., 2013). One of the hypothetical examples used by the teacher to illustrate the concept is depicted in the extract below.

So, now let us suppose if I want to add some impurity to a crystal, I should add an impurity in such a way that it should not affect the structure of the crystal as a whole. Now let us suppose if I am adding a dopant in a Silicon crystal so that Silicon crystal consists of thousands and thousands of Silicon (Si) atoms. Now let us suppose if I remove that Silicon (Si) Atom and place an Atom of extremely huge size there. So, will that huge atom fit into that space? First it will not fit into that space. Secondly if you forcefully try to fit it into that space it will distort the structure of the crystal. Similarly, if you place an extremely small Atom instead of a Silicon (Si) Atom what will happen? There will be a lot of empty space around it. Got it? So that means a suitable dopant is something which will have comparable size more or less it should be of the same size as that of the semiconductor Atom. That is a very important criteria to select a suitable to dopant

Within that lengthy amount of time, another example can be seen when the teacher says:

Then here as you see these are all Silicon atoms but here just one Silicon Atom has been replaced with a pentavalent atom that is a group 5 impurity. It can be anything it can be Phosphorus (P), arsenic (As), Antimony (Sb) so it is replaced with this atom. So, that is how we dope an extrinsic semiconductor, now can even see how does doping increase the conductivity, what changes take place when we add this impurity to the semi-conductor.

The teacher then took the concept back to its theoretical understandings (SG−) after using a number of hypothetical examples to build the concept. In doing so, the teacher manages to generate a semantic gravity wave that moves from weak semantic gravity to strong semantic gravity and back to weak semantic gravity. The diagram below was referred to by the teacher to explain the hypothetical example above. Using Blackie (2014) terms, the teacher is helping the students to form mental associations as she taps into the real-world examples.

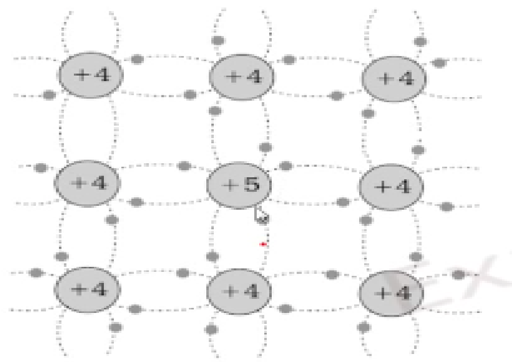


Image 3. Shows an example of a hypothetical example

In an example taken from time interval of 40-50 minutes: The teacher introduced the concept of a p-n junction. The teacher spends a long time at SG− explaining the concept with theoretical statements (weakened semantic gravity), but she does not stop there; she then strengthens the semantic gravity by introducing a hypothetical example. Given that the concept is new to the learners, it could be argued that spending more time explaining the concept is important. Necessary to cumulative knowledge building is the shift to a strengthened semantic gravity over time. The aim of these examples was to show that when the teacher presented new concepts, she either spent a long time explaining the concept theoretically (SG−) or spent more time using examples (SG+) to help learners shift from abstract to concrete understandings. In general, one could argue that the repeated shifts from SG++ to SG+ and SG− over the course of the lesson weakened and strengthened the semantic gravity thus presenting an opportunity for cumulative knowledge building.

5.3.2. Shifts in semantic density (SD) over time in a distance lesson

The teacher starts the lesson by introducing a concept in more accessible terms for the learners. The lesson progresses from a weak semantic density (SD+) to an even weaker semantic density (SD−). As the teacher unpacks the concept of semiconductors by providing learners with a definition: *So, semiconductors are a group of substances which have got some unique characteristics of its own and which can be made useful in various electronic applications*; she makes shifts between SD+ and SD− then back to SD+ (See semantic profile below at 0-10 minutes time interval).

This scenario depicts a situation in which the teacher weakens the semantic density, which is to be expected given that the learners are unfamiliar with the concept. SD weakens when there is a move from condensed meanings to one with less meaning, such as explaining a scientific definition from an academic source in simple terms (Hassan, 2017). We can see the downward shift in the semantic profile below (0-10 minutes) as the teacher reduces the complexity of meaning. In this case, the teacher weakens the semantic density, but she does not stay at a simplistic level of understanding; instead, she repacks the meaning to a strengthened semantic density thus increasing the complexity of meaning. Repacking is denoted by an upward shift in the semantic profile.

The teacher introduces new concepts at a level of strong semantic density but further unpacks the meanings as the lesson progresses. In one instance, the teacher presented the concept of extrinsic semiconductors at a point of stronger semantic density of SD++, where connections between the concept and other ideas are made thus condensing meaning. See extract below.

Teacher: *That means extrinsic semiconductors is further divided into two types depending upon the dopant, which is used; depending upon what kind of impurity is added to the semiconductor. So, if group 5 impurity is added, it is called n- type; if group 3 impurity is added it is called a p-type semiconductor.*

The teacher weakened the semantic density by shifting to SD+, where she explained the concepts in clear and understandable ways for learners, as soon as she introduced the concept at a relatively strong semantic density. The teacher commented on the characteristics and properties of the concepts in this section. The extract below shows a shift from SD++ to SD+. The teacher explains:

N-type is a type of semiconductor where electrons have a negative charge. In p-type semiconductor the effect of a positive charge is created in the absence of an electron. The holes act as the positive charges in this case.

Here, the teacher is giving more characteristics about the concept thus weakening the semantic density. What is really interesting is that most new concepts are introduced at a higher degree of semantic density, such as SD++ or SD+++, and the teacher unpacks the concepts by shifting to SD+ or SD−. As argued by Maton (2013) unpacking density presents a point of entry for learners to understand the condensed meaning embodied within practices. The movement from technicality to more familiar, common-sense vocabulary is referred to as unpacking knowledge (Mcnaught, Maton & Matruglio, 2013). During the lesson, the teacher strengthens and weakens semantic density through a series of shifts between the semantic density codes, resulting in a semantic wave. The following extract depicts a scenario in which the teacher presents a concept with the strongest semantic density (SD+++) and then unpacks it to SD+, thus weakening density (an episode that happens within the time interval of 20-30 minutes)

Teacher: *Let us now discuss p-type semiconductor. In p-type semiconductor we have group 3 impurity. So, a group 3 element would be a trivalent element as it will have the valence of 3 electrons. Let us take the example of a Group 3 elements aluminum (Al). What would be the electronic configuration of Al? It will be:* $1S^2\ 2S^2\ 2P^6\ 3S^2\ 3S^2\ 3P^1$.

To illustrate the properties and characteristics of a p-type semiconductor, the teacher refers to the electron configuration of aluminum. Electron configuration is a condensed symbolic language which explains the principle energy level, number of orbitals and maximum number of electrons around the nucleus. As a result, it is not an easy concept for learners to absorb, thus has the strongest semantic density. Despite the fact that the meaning was condensed and complex, the teacher was able to weaken the semantic density to SD+, where she then proceeded to explain the concept in simple and understandable ways. Maton (2013) states that conveying a scientific expression into a common-sense understanding would decrease the range of meanings, making it much easier for learners to grasp certain meanings. The extract below goes into greater detail about such a case.

Teacher: *So that means in the outer shell which is shell corresponding to n = 3, we have how many valence electrons? We have 3 valence electrons. So, what happens in this case? This is my Al impurity, so it has got 1, 2 and 3 valence electrons (Making dots on the diagram below)*

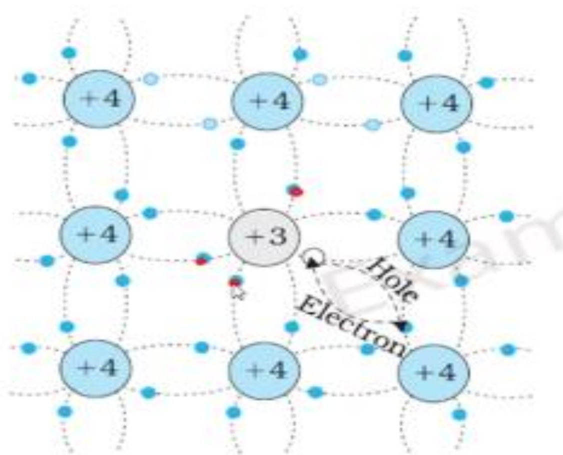


Image 4. Diagram used by the teacher to unpack

Now what happens? As soon as this Al Atom gains one electron the Al becomes a negative ion because it is taking one electron from outside. Before, it was neutral but as soon as it takes one electron from outside that means it is taking an additional negative charge, so it becomes negatively charged. But since it is involved in the covalent bonding therefore it cannot move, even though it is a negative ion, but it cannot act as a charge carrier because it is immobile it is fixed at one place because of the bond formation on all sides

The semantic profile shown below depicts a continuous wave in which the teacher moves between the semantic density codes through downwards and upwards shifts over time. The repeated movements of strengthening and weakening semantic density creates the necessary conditions for cumulative knowledge building. The downward shift in necessary as it introduces learners to the simple meanings condensed within concepts while the upwards shift is crucial as it helps with addressing the knowledge build within practices (Maton, 2013).

Semantic profile showing shifts in semantic density – distance lesson

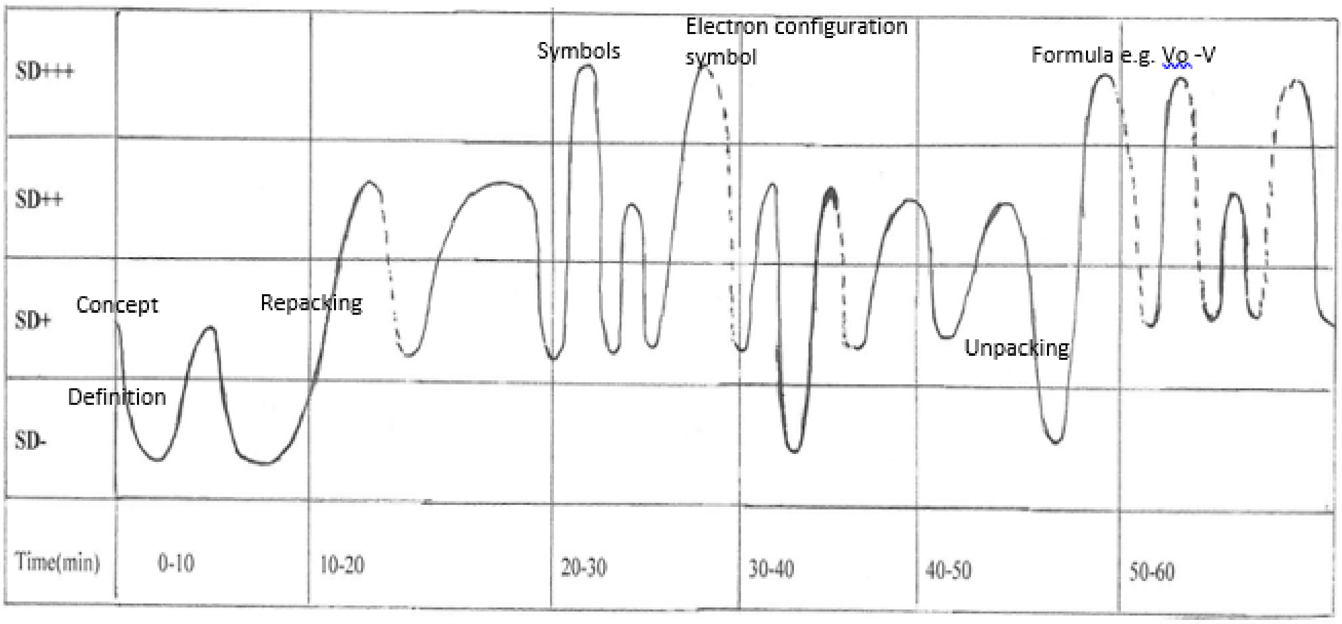


Figure 7. Shows shifts in semantic density of a distance lesson over time

5.3.3. Shifts in semantic gravity (SG) over time in a contact lesson

The teacher starts the lesson by introducing the concept of semiconductors with a theoretical statement that contains a lot of abstractions. In other words, the lesson starts with a very weak semantic gravity (SG−), indicating a situation in which meaning is not linked to any particular context. See extract below (depicted by the time interval of 0-10 minutes in the semantic profile below).

Teacher*: The last lesson was about extrinsic semiconductor where we introduced doping as a method of increasing conductivity in semiconductors. Can you tell me what is doping from the previous lesson? What did I say about doping? Yes?*

The concept of doping as a method of increasing semiconductor conductivity is an abstract principle that requires a simple unpacking with the use of examples that illustrates how doping occurs and the details that lead to increased conductivity. Because the statement presents a recap from the previous lesson, it's reasonable to assume that learners already understand the concept. However, semantic gravity is about how context bound or abstract the meaning presented by the teacher is, rather than situating meaning in terms of prior learning. The teacher then unpacks the concept by bringing in a hypothetical example; that helps learners to construct mental images based on the theoretical statement that is presented to them. The shift in semantic gravity from SG– to SG+ creates a downward curve in the semantic profile (see semantic profile below at time interval 0-10 minutes), illustrating a move from context independent to context dependent meanings (Maton, 2013). Using a hypothetical example from her own statement (Silicon crystals) and (As) from the learners, the teacher strengthened the semantic gravity. See extract below.

Teacher: *You include, we actually bring in the foreign element. You still remember the alien element? Silicon crystals if you still remember. So, we had some silicon crystal with electrons around it and we introduced a certain element. Which element? Can you remember? There was an alien- a foreign element that we used.*

Learner: *As*
Teacher: *We used what? As which is what? Arsenic…and in which group is Arsenic if you look in your period table right now? It's in group?*
All learners: *15*

In two ways, this episode portrayed a rare phenomenon of SG+: One; the teacher uses a hypothetical example (As) that was presented by the learners. Two; the teacher directs the students to check their periodic tables, making learning more context-dependent. It is almost as if the teacher is saying, "We have the periodic table here, so we are going to use an example from the periodic table that is right in front of us to help you understand the concept better". This example illustrates the benefits of contact teaching where learners' interaction with the content is increased. Moreover, the teacher does not leave the meaning at SG+ (strengthened semantic gravity), but instead weakens it by repacking it to the abstracted level of SG– (See extract below).

Teacher: *So, if we pair the four electrons around the Arsenic what we end up having is one free electron and because of the free electron that is able to move around, we say it forms a certain type of semiconductor which we call it a what? An n-type. What did we say about this n, what does n stand for?*
Learners: *Negative*

The conditions for cumulative knowledge building, are established by the movement between strengthening and weakening SG (Maton, 2013a). The actions of strengthening and weakening semantic gravity allows the teacher to make explicit links between abstract ideas and familiar examples. According to Byers (2019) the actions that teachers take allow their learners to comprehend disciplinary knowledge, which in turn influences knowledge building.

Semantic profile showing shifts in semantic gravity – contact lesson

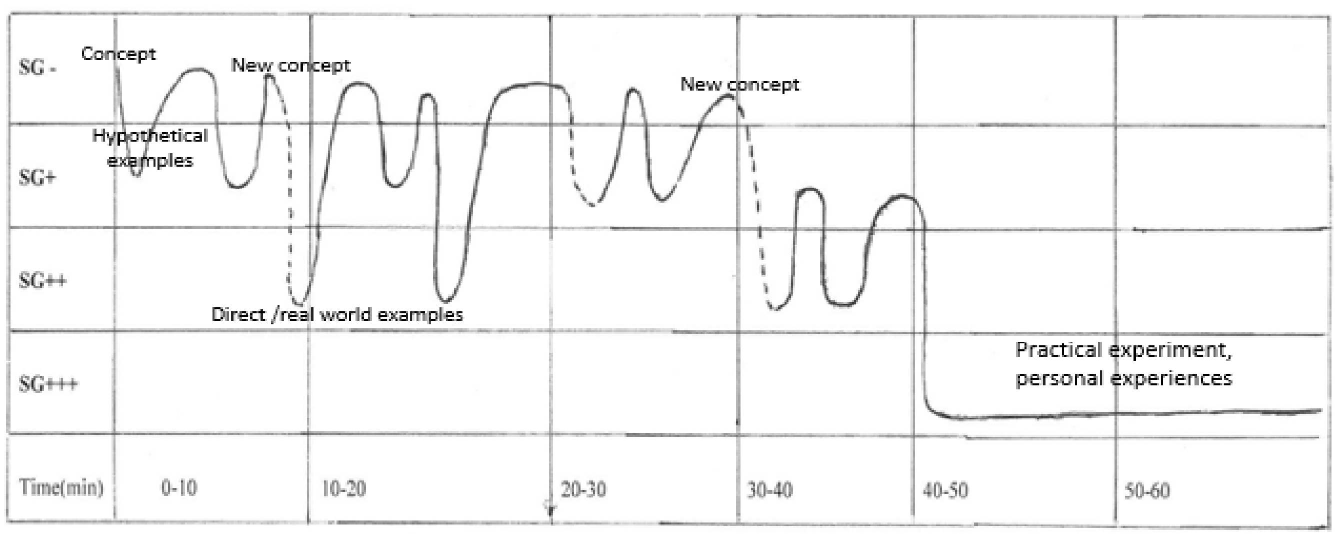


Figure 8. Shows shifts in semantic gravity of a contact lesson over time

As seen from the semantic profile above, the teacher unpacks and repacks the concepts as the lesson proceeds, moving between SG−, SG+, SG++, SG+++, and back to either codes. Maton (2014a) argues that the answer to academic success is not having a stronger or weaker SG, but rather having a wider range of movement between them. In this lesson, the teacher consistently weakens and strengthens the semantic gravity to its maximum ranges. Similarly, to the distance lesson, new concepts are presented at a weakened semantic gravity, the teacher however unpacks the concepts by using both hypothetical and direct examples denoted by SG+ and SG++. The extract below is from the 30-40 minutes period, and it shows how the teacher unpacked a new concept as she progressed from a weaker semantic gravity (SG−) to a stronger semantic gravity (SG++).

Teacher: *Since there won't be movement of electrons we say this is not a forward bias but a reverse bias. The reason why we say its reverse bias is because there won't be any conduction.*

The preceding statement is a theoretical and abstract statement that illustrates a valid premise for the concept of reverse bias in semiconductors. The semantic gravity of this statement is weakened since it explains abstract and context-independent meaning (Curzon, Maton, Waite & Donohue, 2020). The ability of the teacher to tap into the learners' real-life experiences by using examples that learners can visualize to create mental images is critical to academic achievement. Blackie (2014) suggested that as teachers, we can assist students in reaching abstraction, but we must continue to dip back to their experiences so that students can develop mental associations. Following this argument, the teacher is able to move from SG− to SG++ in the lesson when demonstrating to learners how biasing in semiconductors works.

Teacher: *Anything that you want to know about that? Who can tell me? When will this stop? The positive and negative terminal will keep on attracting the holes until when? What do you think?*

Teacher: *Until the battery is dead - flat. As long as there is more electrons and the battery is strong enough it can go forever and keep on attracting them. There is no way, it's like you trying to jump and someone is pulling you, they keep on pulling you and pulling you, further and further away from the region* (at *this point in time the teacher is demonstrating the pull effect with the learners).*

The above statements portray the use of a direct experience that strengthened the semantic gravity; however, the teacher does not stop there; instead, when the shift to SG− occurs, the teacher further weakens the semantic gravity. As argued by Maton (2014a) and Maton (2013) semantic gravity is weakened when there is movement from the concrete particulars of a case towards generalizations and abstractions where meaning is not closely related to its context. SG must be weakened in order for cumulative learning to occur (Maton, 2009).

Looking at the above semantic profile, we can see a situation where the lesson progression remained at SG+++ for a long time (40 – 60 minutes), resulting in a flat-line towards the end of the lesson. In this study, SG+++ refers to a situation in which the teacher focuses on personal experiences and examples. As a result, the question arises as to what was going on at the time.

Learners were exposed to a practical experiment (at the 40-60 minute mark of the lesson) to help them understand what happens in reverse and forward biasing. Learners were actively engaged with the materials and responding to the teachers' questions. As shown in the extract below, I summarized what happened during the lesson and the pictures of the learners working on a practical experiment are shown below.

Throughout this point in time, the teacher is explaining how learners can conduct this small practical using the LED, resistor, battery and multi-meter to illustrate the reverse and forward bias. There are discussions within the group and the teachers is moving around asking learners questions. 'Is this a forward or reverse bias?' How do you know? Is there any light from the LED?
The learners responded by stating that there is a reading on the multi-meter, therefore that is a forward bias and when there is no reading it is reverse bias. Leaners further stated that when the LED glows it shows that current is moving, then that is a forward bias and when there is no light it is a reverse bias.

Image 5. Shows the materials presented for learners as they worked on a practical experiment.

Image 6. Shows learners working during the practical experiment

This scenario portrays a very strong semantic gravity (SG+++) where learners were introduced to a practical activity which enhanced their personal experiences in working with the concepts. Asking experience related questions strengthened the semantic gravity. As noted by Blackie (2014) asking questions allows for SG to be strengthened. Summer (2009) argues that a science teacher enhances the learning environment by making science classrooms inclusive of learners' ideas and helping learners connect science to their daily lives. Hassan (2017) also argued that learners are more likely to engage with the content when they are asked probing questions. "Is this a forward bias? How do you know?" inquired the teacher. Learners would draw from the practical and the concepts presented throughout the lesson to answer the questions. To further clarify why the practical experiment denoted a very strong semantic gravity, learners were further required to talk about their experiences of conducting the practical thus making meaning more context dependent. See extract below.

Teacher: *How was your experience of using the diodes and seeing the reverse and the forward bias?*
Nelson: *It was interesting to see current flowing*.
Teacher: *Good*
Teacher: *Can someone from the next group share their experience?*

Kutlwano: *Sometimes it is scary because you are thinking what if I break these things.*
Teacher: Okay. That is the only problem. Can anyone from this group tell us their experience?

Sam: *We had a fault with our LED because it did not light up, we think the problem could have been the battery. We are hoping that we redo and see how it actually works out*.

Teacher: *Can another group send their materials so that this group can quickly see the forward bias and reverse bias using the LED. Let us give them a chance before we move on.*
(The group is given a chance to redo the practical and their LED lights up).

Learners in the group: *That is the forward bias! The other way around it means the LED won't light up so that will be the reverse bias.*
Teacher: *True*

The above scenario depicts a situation in which the teacher tapped into the learners' personal experiences thus enhancing conceptual understanding. According to the (South African Council for Education (SACE final draft PTs for Gazette, 2018), teachers must be able to develop coherent sequences of learning experiences for their learners and understand how subject knowledge can be used to interpret and address real-world problems. The teacher progressively weakened and strengthened semantic gravity throughout the lesson. This constant movement, combined with the increased semantic gravity range, resulted in a continuous wave, which is an important feature for accumulating knowledge (Maton, 2013).

5.3.4. Shifts in semantic density (SD) over time in a contact lesson

The lesson begins with a strengthened semantic density of SD+, as the teacher presents the concept of semiconductors using subject terms which are explained in an understandable manner for the learners (*Interval of 0-10 minutes from the semantic profile below*). As the lesson progresses, the teacher weakens the semantic density by shifting to SD− , where the concept is conveyed in a straightforward manner that a non-subject expert can understand. The action of unpacking the concept or weakening the semantic density presents an entry point for the learners into the complex meanings of the concept presented (Singh et al., 2013). In unpacking, technical terminology is explained in simple terms thereby causing a downward shift in the semantic scale. The teacher does not leave meaning in its most basic forms; instead, she shifts back to SD+, allowing for a revived strength in semantic density.

Semantic profile showing shifts in semantic density – contact lesson

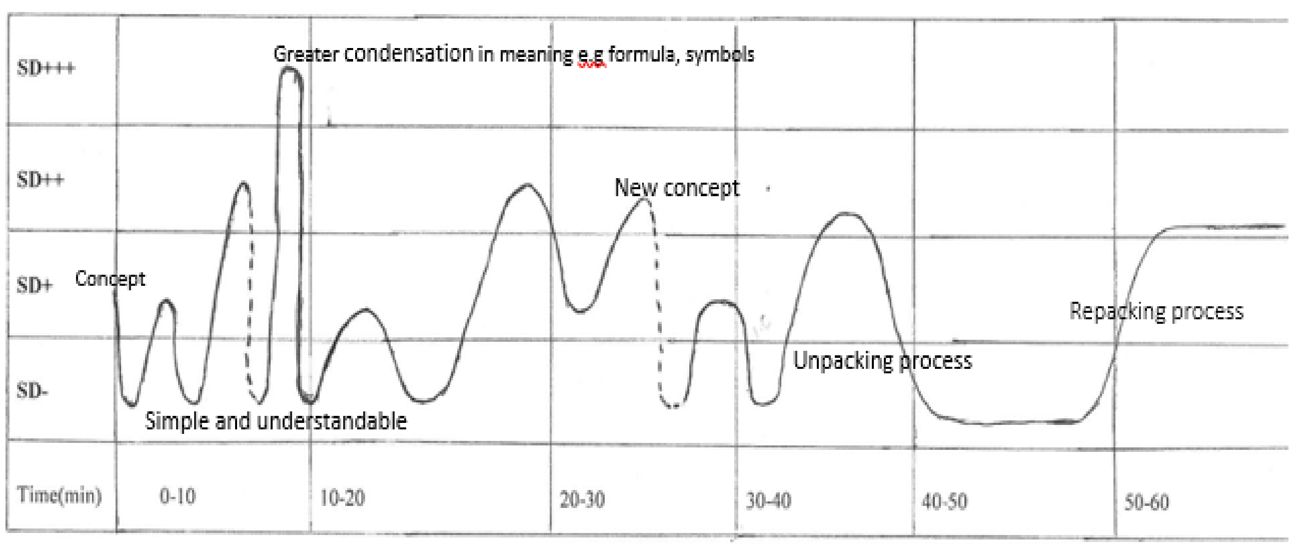


Figure 9. Shows shifts in semantic density of a contact lesson over time.

From the semantic profile above, it is clear that the teacher shifts between the semantic density codes as the lesson progresses, either by strengthening or weakening semantic density thus depicting actions of unpacking and repacking. According to Maton (2014), the downward shift (SD−) is critical in inducting learners into the condensed meanings embodied within practice, while the upward shift (SD+) is equally important in addressing the constellations of meaning within condensed terms.

The following extract is also from a 0-10 minute period in which the teacher presents a concept in a condensed manner with a greater level of complexity using symbols (SD+++). The teacher does not leave the meaning in its condensed form, but instead weakens it to SD+, where the concept is explained in a way that is understandable, and then to SD−, where the semantic density is the weakest. The series of these actions thus conform to the roles of the teacher as depicted by the professional teaching standards (PTs) where it is argued that teachers need to explain disciplinary knowledge to learners in ways that are understandable and accurate.

Teacher: *So, this is the symbol of a diode* (Draws the symbol on the board)

If you look at the next diagram in the next activity you will realize that a diode has this kind of symbol. Where this one presents a positive (Referring to the diagram above) and we sometimes call it a what? An anode. And the symbol of an anode is A. And this one a negative we sometimes call it a cathode; a symbol of a cathode is K

From the above scenario, the teacher gives explanations which denotes symbols. Symbols represent condensed meaning for an object thus making it complex for learners to understand. In weakening the semantic density, the teacher makes a shift to SD+ where she gives more details about the characteristics and properties of the object. While using the learners' responses the teacher further moves to SD− which represents a weakened sematic density.

Teacher: *But today in our lesson we will be using two types of diodes, okay, I will be showing you the two types of diode. We will be using the first diode called the ordinary diode (*Shows learners the macroscopic representation of a diode*). We are going to see when we use it in a group. That grey part is a positive side and the black side is the anode side. Another type of diode that we will be using today is called LED. I don't know if it's for the first time you hear about that. It's called LED, why is called LED? This is just the abbreviation* (writes the abbreviation on the chalk board)
Anyone who knows what is LED?

Learner: *Light emitting diode.*
Teacher: *Yes, it's a light emitting diode. Why do we call it a light emitting diode? What's the reason behind that? Can you raise up your hand and tell me?*

Learner: *I think it's because when both charges (negative and positive) come together that's when the light will glow.*
Teacher: *Yes, it emits light. Excellent! The reason why we call it LED is because when it is connected it's actually showing a light that's why the symbol for LED makes use of the arrow to show that it means light.*

The semantic profile above indicates that as the lesson progressed, new concepts were introduced at a higher degree of semantic density (SD++). New concepts in the semantic profile are represented by dotted curves. It's unsurprising that as soon as the new concept was introduced, the teacher weakened the semantic density by offering a simplified understanding of the concept; in doing so, the teacher unpacked the concept causing the semantic wave to curve downward. Unpacking density, according to Singh et al. (2013) provides a point of entry for learners into the dense meanings of concepts.

In addition, as the lesson progressed, the teacher remained at SD− for a long time towards the end of the lesson (see interval 40 -50 from the semantic profile above) before shifting to SD+, where the lesson ended. In this case, we can see how the teacher progressed from a weak semantic density to a stronger semantic density over time. The students were performing a practical experiment to understand the idea of reverse and forward bias at this point in the lesson, and the teacher made sure that the concepts were clarified in a way that the students could understand, thus weakening the semantic density (denoted by SD−). The teacher then shifted from SD− to SD++, where she clarified the concepts in a more understandable manner, including more details about the concepts' characteristics and properties. See the extract below.

Teacher: *See, in reverse bias our LED will not glow up and the multi-meter will not show any reading because there is no conduction. Remember conduction is the movement of electrons, this means that in reverse bias electrons are not able to move as I explained earlier. But in forward bias our LED glows up and the multi-meter shows a reading because there is conduction.*

The teacher ended the lesson with the above statement, which summarized and explained the concepts that had been discussed. In conclusion, throughout the lesson, the teacher made continuous shifts between all of the semantic density codes, resulting in a semantic density wave, which is a feature of cumulative knowledge building. According to Blackie (2014) to build knowledge, a science teacher should explicitly make the invisible visible by shifting learners from complex-abstract understandings to simple and concrete understandings over time.

5.4. Findings on similarities and differences in the semantic profiles of the two lessons

The findings that are presented here are drawn from the aspects that were addressed by the main research question: *How does cumulative knowledge building take place in a lesson taught though distance and contact sessions?* To create an easy to follow structure for the presentation of these findings I will first look at the semantic profile for the shifts in semantic gravity (SG) on both lessons, stating the similarities and differences. Thereafter, I will address the similarities and differences for the shifts in semantic density (SD) profile for both lessons. The profiles for both semantic density and gravity in both distance and contact lessons are characterized by semantic waves rather than flat-lines or down escalators.

5.4.1. Similarities and differences in semantic gravity waves (SG) – comparing the semantic gravity waves.

One of the key similarities between the distance and contact lesson was that both lessons demonstrated a continuous movement between the semantic codes, resulting in semantic gravity waves that progressed from beginning to end. Maton (2013) states that semantic gravity waves represent the pulse of cumulative knowledge building that involve the shifts in context-dependent and decontextualized meanings over time. While both lessons had a range of shifts between the semantic codes, it's worth noting that the contact lessons' semantic wave had shifts from SG−, SG+, SG++, and SG+++, while the distance lessons' shifts were defined by movement between SG−, SG+, and SG++. In other words, the contact lesson teacher extended the semantic gravity range by focusing on personal experiences which present the strongest semantic gravity. This was achieved when learners conducted a practical experiment and then outlined their experiences of the practical.

Shifts in a distance lesson were dominated by a move from SG− to SG++, indicating that the teacher was mostly able to present concepts in theoretical and abstract ways while still bringing the meaning closer to the learners' everyday lives through the use of hypothetical examples. In comparison to the contact lesson, the semantic gravity wave was aligned on the top part of the semantic scale. Contrary to the distance lesson, shifts in semantic gravity for the contact lesson ranged from SG− with the codes SG+, SG++ and SG+++ being repeated often. This indicates that the teacher was able to use hypothetical, direct, and personal examples to aid learners to understand abstract concepts.

In both distance and contact lessons, new concepts are introduced at a high level of abstraction (SG−) with the teachers spending a significant amount of time explaining the concepts before unpacking. This helps learners make mental associations between abstract and concrete knowledge. Although this is the case, it remains notable that the unpacking for the contact lesson extended to a much strengthened semantic gravity of SG+++ as compared to the distance lesson. Looking at how both lessons start, the distance lesson semantic wave starts with a strengthened semantic gravity of SG++, where the teacher first introduced a direct example to the learners while the contact lesson semantic wave started off from a weaker semantic gravity were the teacher first introduced a theoretical and abstract statement. As argued Maton (2013) waves take multiple forms, they may begin with abstract or concrete knowledge and vice versa, however the important feature that characterizes cumulative knowledge building is the continuous shifts in semantic codes over time.

5.4.2. Similarities and differences in semantic density waves (SD) – comparing the semantic density waves.

Much like the semantic gravity waves both lessons demonstrated a continuous wave that shifted from simplified to clear meanings over time. New concepts were introduced at a level of stronger semantic density in both lessons, and then further unpacked thus weakening the semantic density. The teacher made more shifts between SD+++ and SD+ in the distance lesson than in the contact lesson, where the teacher only made one shift from SD+++ to SD− in the overall lesson.

Both lessons begin at SD+ which signifies a strengthened semantic gravity and shifts are made to SD− indicating a scenario were both teachers weaken the semantic density to allow an entry point to the condensed meaning for the learners (Singh et al., 2013). Furthermore, both lessons end with a greater degree of semantic density (SD++). The endings of the two lessons vary in two ways: the distance lesson ends with a downward curve depicting an unpacking situation, while the contact lesson ends with an upward curve portraying a repacking situation.

5.5. What the semantic ranges of the two lessons reveal about the potential for cumulative knowledge building

A semantic range is described as a series of significant shifts from stronger semantic density or weaker semantic gravity to weaker semantic density or stronger semantic gravity, and so on (Maton, 2014a). Semantic ranges speak to the ability to wave (Clarence, 2013) as seen from the gravity and density profiles for both lessons. There is a need for lessons to have a greater range rather than small semantic ranges as this presents a situation where teachers align meaning with students' lived experiences (SG+ / SD−) and meaning further addressed within the abstract and condensed terms (SG− / SD+) (Maton, 2013). Looking at both lessons, shifts in semantic gravity and density revealed great waving which depicted greater possibilities for cumulative knowledge building.

The semantic gravity range for the contact lesson appeared to be greater than that of the distance lesson, despite the fact that both lessons provided great opportunities for cumulative knowledge building. A change from SG− to SG+++ characterized the greater range in a contact lesson, while a shift from SG− to SG++ defined the semantic gravity range in a distance lesson. The contact lesson teacher expanded the semantic gravity range by introducing concepts at a more context-dependent level, in which learners took part in a practical experiment that revealed how theory can be applied in practice. Dorfling, Wolff and Akdogan (2019) found that extending the semantic range allows learners to apply what they have learned in the real world. Regardless of the fact that the study by Dorfling et al. (2019) focused on chemical engineering students and expanded the semantic range to include site visits, the findings of this study can be placed within that scope. The relationship between semantic ranges and cumulative knowledge building shows that expanding the semantic range increases the possibilities for cumulative knowledge building. As such the contact lesson revealed an extended semantic gravity range as compared to the distance lesson. Practical experiments, according to Pott and Wolff (2019), pull learners towards a stronger semantic gravity. The semantic profiles below show the differences in the semantic gravity ranges for both lessons.

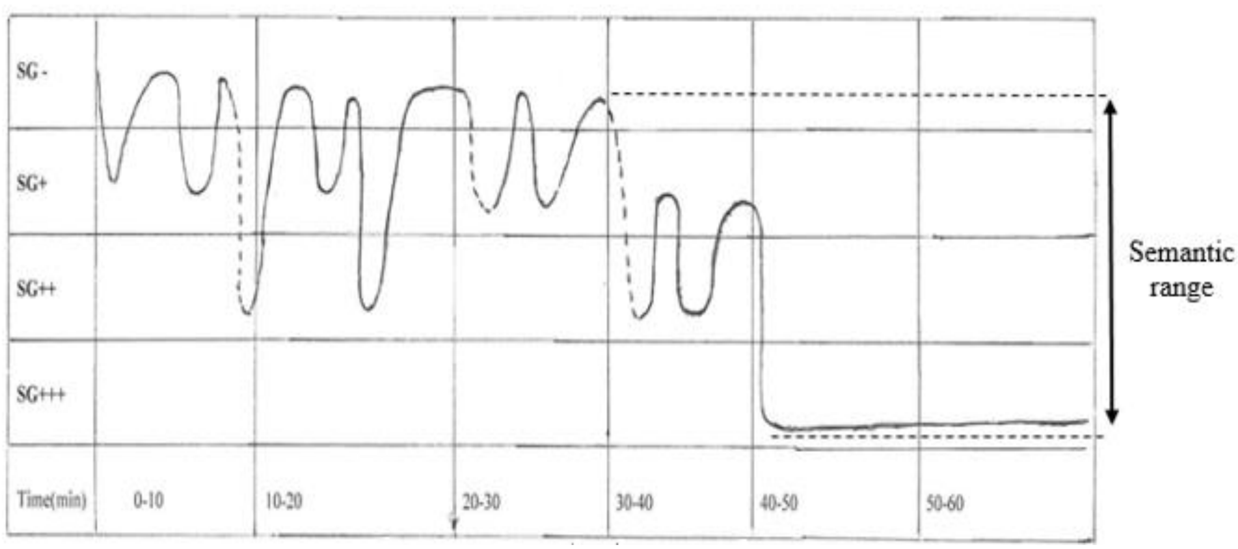


Figure 10. Higher semantic gravity range for the contact lesson

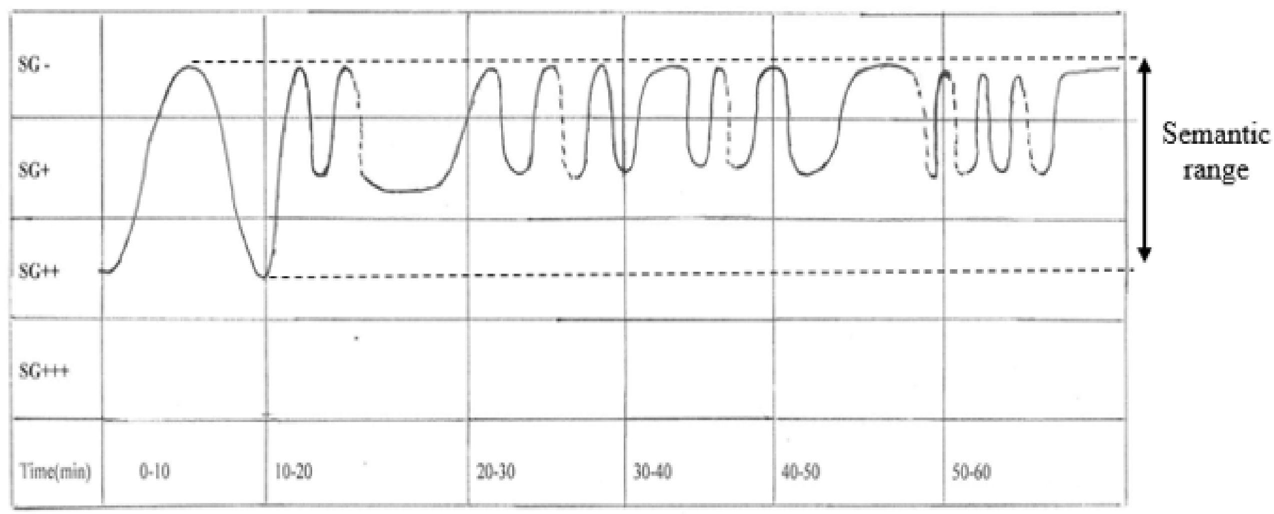


Figure 11. Lower semantic gravity range for the distance lesson

The findings demonstrate that both lessons have a great potential for cumulative knowledge building when looking at the semantic density waves. Over the course of the teaching, both teachers were able to move from SD+++ to SD− thus creating a bigger range. The semantic waves below show similar ranges of semantic density (SD) in both lessons.

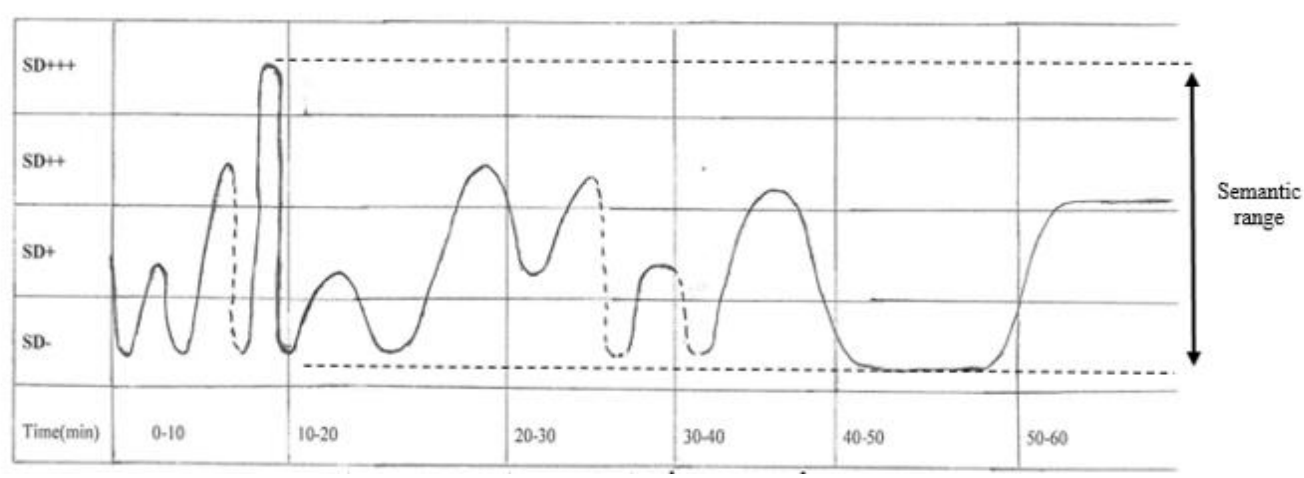


Figure 12. Semantic density wave for contact lesson

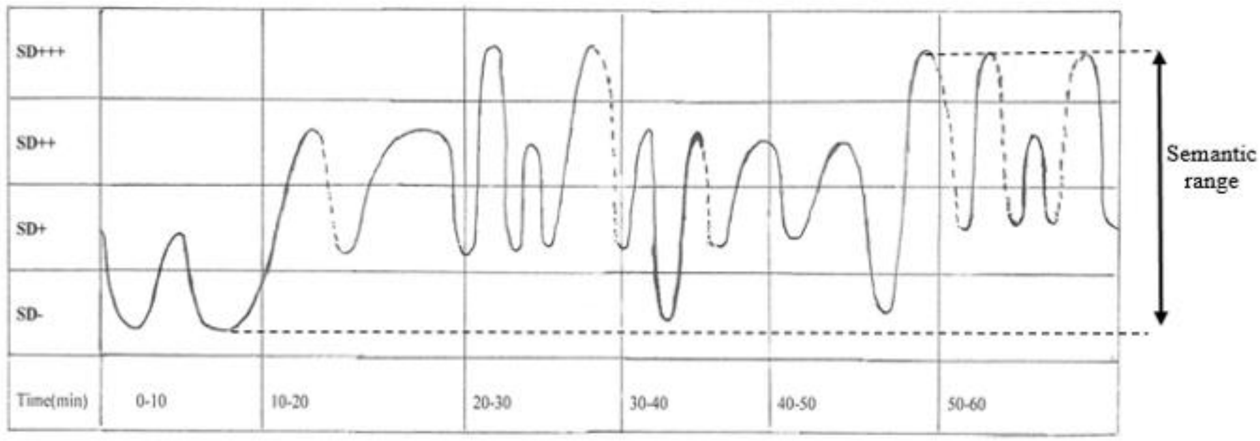


Figure 13. Semantic density wave for the distance lesson

When the semantic ranges for gravity and density for both lessons are compared, one would be inclined to argue that the contact lesson has a greater potential for cumulative knowledge building because the semantic gravity range is greater. Despite the fact that the contact lesson allowed for a greater semantic gravity range, both lessons showed significant movements between SG and SD, as a result, the findings cannot be reduced to simply stating that the contact lesson has a greater capacity for cumulative knowledge building because a small element set these lessons apart. Semantic waves, according to Maton (2014), are described by repetitive movement in context-dependence and meaning condensation. Both lessons exhibited great waving between semantic codes, thus demonstrating great potential for cumulative knowledge building. According to Blackie (2014), a science teacher should clearly make the abstract visible by moving learners from a complex-abstract understanding to simple and concrete understandings over time in order to build knowledge; both lessons adhered to this point.

With the exception of semantic gravity range, both lessons demonstrated excellent waving and ranges that were quite similar. Singh et al. (2013) argue that the secret to unlocking cumulative learning and progression is semantic waves. The semantic waves show that the teaching for both lessons provides almost identical opportunities for cumulative knowledge building. The question thus remains, "What sets these lessons apart?" Perhaps having a better understanding of how both teachers work with learners will allow me to draw more definitive conclusions. As a result, I will now briefly explore how both teachers interact with learners as knowers of the subject; in other words, how teachers induct learners into thinking and behaving like scientists.

5.6. Building learners as knowers of science

There was no clear moment in a distance lesson where the teacher made explicit what counts as achievement in learning science, however, in the contact lesson, the teacher specifically introduces learners to the tasks of a scientist and provides direct guidance about what they are doing well and what they need to improve on. When learners were doing a practical experiment, the teacher shaped their knower gaze by specifically showing them that practical work is a form of a trial and error, and that when the results contradict the theory, they must redo the practical to verify the results. Below is an extract from the contact lesson.

Teacher: *Can others share their experiences? What can you say about the multi-meter? Is there forward bias in the multi-meter?*

Learner: *There was a reading for the reverse bias.*

Teacher: *Let's redo the practical to see if you are telling us the truth.*

Learners redo the practical and later realize that there is no reading for the reverse bias only in the forward bias.

Teacher: *See it means your group didn't do it right. Now listen class, the next activity is coming and we moving back to our positions. This will be a small activity for about ten minutes on your own. Okay?*

Clarence and Mckenna (2017) emphasizes the importance of learners being aware of the types of knowledge and skills they should possess when learning a subject. The teacher must be explicit about how they are molding the learners into the tasks of a scientist. Developing learners into knowers of the subject provides them with the skills they need to succeed in that subject. Learners in science need to be clearly shown the skills along with the knowledge in order to make correlations between content and practice and later transfer the knowledge to other contexts. In light of the contact lessons' ability to cumulatively build knowledge and also cultivate learners as knowers of the subject (building knowers), it's reasonable to conclude that the contact lesson provided more opportunities for cumulative knowledge building and cumulative learning. According to Macken-Horarik (2011), both content and process are important. The key to cumulative learning is making connections between the content and knowing how, which in turn cultivates learners as knowers.

5.7. Chapter Summary

The findings were presented in detail in this chapter, and they had been interpreted in light of the conceptual framework and bodies of literature that informed this study. As the chapter addressed each research question individually, the research questions were explicitly answered and explained. The findings revealed that both lessons had maximum opportunities for cumulative knowledge building, making it difficult to draw specific conclusions. However, focusing on how teachers develop learners into subject knowers resolved the tie, as it was clear that the contact lesson had more capabilities of inducting learners into the scientists' work and thereby improving understanding and learning and consequently making learning relevant for the learners. The contact lesson teachers' ability to build the knower code, as well as the extended semantic range shown in the semantic wave for gravity, lead to the inference that the contact lesson demonstrated advanced cumulative knowledge building on the topic of semiconductors for Grade 12 learners.

CHAPTER 6: SUMMARY OF FINDINGS AND CONCLUSIONS

6.1. Introduction

The previous chapter presented and interpreted the findings of this study. The aim of this chapter is thus to summarize the overall findings. To do so, I will provide a brief overview of the most important findings, as well as some conclusions drawn from the interpreted data. In addition, this chapter will outline the recommendations, implications, and limitations of the study. The overall purpose of this study was to compare how cumulative knowledge building occur in a lesson taught through contact and distance means in technical sciences on the topic of semiconductors for Grade 12 learners. The goal of this study was to answer the following main research question: How does cumulative knowledge-building take place in a lesson taught though distance and contact sessions? The following sub-research question were addressed:

a. What are the similarities and differences in the semantic profiles of the two lessons?
b. What do the semantic ranges of the two lessons reveal about their potential for knowledge-building?

The findings are summarized below using the three research questions that guided this study.

6.2. Research findings:

6.2.1. How cumulative knowledge building takes place in a lesson taught through distance and contact session?

The findings of this study revealed that there were continuous semantic waves in which both teachers made significant shifts between stronger and weaker semantic gravity and density. The lessons indicated a series of strengthening and weakening of semantic gravity and density over time. When it comes to semantic gravity (SG), both teachers were able to move from abstract concepts to concrete and context-dependent examples, strengthening semantic gravity. Both teachers further moved up from concrete examples to more abstract ideas, weakening semantic gravity. By strengthening and weakening the semantic density (SD) over time, both teachers were able to unpack dense concepts by putting them into simple and understandable forms for learners. They were also able to shift from simple and understandable meanings to condensed symbolic language, which characterizes scientific concepts.

Maton (2013) argues that the strengthening and weakening of SG and SD is critical in connecting students to real-life experiences while also addressing the meanings embodied in abstract and condensed concepts. Maton (2013) further argues that semantic waves, which are key features of cumulative knowledge building, are generated by repetitive movements between strong and weak semantic gravity and density. The ability of both teachers to generate waves has been observed as a means of overcoming knowledge segmentation, which is described as knowledge that is too closely linked to specific contexts and too fragmented to build on prior knowledge, resulting in students learning segmented ideas or skills. The business of teaching is to create waves whereby the semantic range of knowledge is expanded and abstract concepts become both visible and meaningful in a number of contexts (Walton & Rusznyak, 2019).

6.2.2. Similarities and differences in semantic profiles of the two lessons

Both lessons' semantic profiles demonstrated a semantic wave, which is an important feature for cumulative knowledge building. It's worth mentioning that both lessons introduced new concepts at a high level of abstraction (SG−) and complexity (SD++ or SD+++). The teachers did not leave meaning in abstract and condensed forms; instead, they would spend time unpacking the concepts in simple terms while using concrete examples. As Blackie (2014) argues, teachers must support learners in reaching abstraction while also dipping back to allow learners to form mental associations.

Cumulative learning is described as a situation in which teachers provide learners with an entry point into the meanings embodied in abstract and condensed concepts. The results lead me to a significant point: scientific concepts are part of the objective disciplinary knowledge reflected within curriculum; thus, teachers must unpack scientific knowledge while still teaching the expected scientific concepts as mandated by the curriculum. As much as science textbooks require teachers to work with complex scientific knowledge, it is also important that teachers create an entry point for learners into the complex and abstract meanings. The point explains why the move from SG− / SD+++ to SG+++ / SD− is crucial. For conceptual understanding to occur knowledge cannot only be reduced to objective and abstract understanding for learners; such a situation leads to knowledge segmentation.

Another similarity between the two lessons is the semantic density ranges (SD). Both lessons had a great sematic density range, which was defined by a shift from SD− to SD+++ over time. The notable difference is in the semantic gravity ranges (SG). The contact lesson had a larger semantic gravity range, indicating a significant shift from SG− to SG+++, while the distance lesson had a range indicating a shift from SG− to SG++. The contact lesson teacher was able to extend the semantic gravity range as compared to the distance lesson. According to Maton (2014a), the secret to academic success is not having stronger or weaker SG, but rather extending the range of movement between them.

6.2.3. What the semantic ranges of the two lessons reveal about the potential for cumulative knowledge building.

The semantic density (SD) ranges of the two lessons were similar, while the semantic gravity (SG) ranges were different. Focusing on the semantic density (SD) ranges, both lessons reveal great opportunities for cumulative knowledge building. However, based on the semantic gravity ranges (SG), the contact lesson appears to have a lot of potential for cumulative knowledge building. The fact that the teacher extended the semantic gravity (SG) range in the contact lesson by using personal experiences in the form of a practical experiment, indicate the importance of linking abstract meanings to concrete examples. Summer (2009) states that the role of a science teacher is to help learners connect science to their daily lives. Maton (2014a) states that SG is necessary for cumulative learning since new knowledge should be built on and combined with previous knowledge in order for knowledge to be transferred through contexts, which is a requirement for accumulated knowledge (Maton, 2009).

The contact teachers' ability to integrate personal experiences and invite learners into science learning skills enhanced the lessons' ability to build cumulative knowledge. Despite the fact that the semantic density (SD) ranges were similar, combining the SG and SD ranges results in the contact lesson having more opportunities for cumulative knowledge building. The use of a practical experiment to extend the semantic range of the contact lesson raises the question of how far distance lessons may work with practical experiences to enhance learning. Such insights lead us to consider the benefits that contact lessons can provide in terms of teaching and learning. According to Bagheri and Zenoughzagh (2021) contact lessons have increased chances of social and academic engagement with the learners; the findings further support the argument brought forward by Bagheri and Zenoughzagh (2021).

In chapter 5, I mentioned that comparing semantic (SG) ranges cannot be the only factor that leads to the conclusion that the contact lesson has greater cumulative knowledge building capabilities. Since both lessons showed great potential for cumulative knowledge with a minor distinguishing factor of semantic gravity range, doing so would render the findings inconclusive and misleading. As such, I turned my attention to how both teachers developed learners as science knowers. The findings showed that there were no explicit moments in the distance lesson where the teacher inducted the learners into science skills and processes. However, there are instances in the contact lesson where the teacher shapes learners into working and acting like scientists; the instances further outlined what counts as achievement in learning science. In the contact lesson the teacher explicitly developed learner conceptual understanding and skills as learners were guided into the processes of the practical experiment. In so doing the teacher extended the semantic range and also worked progressively in building learners as knowers of science. Such occurrences contribute to academic achievement and are critical to cumulative knowledge building.

6.3. Implication(s) and recommendations for future research

One of the most important differences between the two lessons is the semantic gravity range, which was extended in the contact lesson as a result of a practical experiment performed by learners and the contact teachers' ability to develop learners as science knowers. The findings have important implications for practice. The findings point to the need for distance lessons to be organized in a way that accommodates learners' personal experiences in the form of practical experiments and explicit development of learners into science knowers. The reality remains that COVID 19 has altered the nature of teaching and learning; as a result, teachers must employ techniques that are most successfully accomplished by contact teaching in distance lessons too. Teachers must respond to changing global demands while maintaining the quality of their teaching. It's worth noting that in this study, distance teaching took the form of pre-recorded videos that were published for learners to access. Further research should be done to explore how a variety of distance modes of teaching, such as live online lessons, build cumulative knowledge and respond to the aspect of developing learners into knowers of science. Given how little is known about cumulative knowledge building in technical sciences in particular, further research that expands the scope of this study would be extremely beneficial.

6.4. Limitations of the study

Considering that semiconductors are a relatively new topic in the South African curriculum, it is important to understand the depth of the teachers' content and pedagogical knowledge when teaching this topic. However, the qualifications of both teachers in this study were unknown, making it difficult to understand and oversimplify their ability to teach the topic. Furthermore, since the learners' background was unknown, it was impossible to make conclusions about the nature of the examples and approaches used by the teachers. Since this was a case study, the findings cannot be generalized to the entire population of technical science Grade 12 teachers; instead, they are confined to the participants of this study.

6.5. Conclusions

Both teachers displayed significant waving and similar ranges, with the exception of the semantic gravity range, which seems to indicate that their knowledge building was very similar. This suggests that both teachers' lessons have almost equal opportunities for cumulative knowledge building. However, when considering the expanded semantic gravity range of the contact lesson and the teachers’ ability to develop learners into subject knowers, it can be argued that the contact lesson provided more opportunities for cumulative knowledge building.

References

Ananga, P., & Biney, I. K. (2017). Comparing face-to-face and online teaching and learning in higher education. *MIER Journal of Educational Studies Trends & Practices*, 165-179.

Anderson D (2002) Reforming Science Teaching: What Research Says About Inquiry, Journal of Science Teacher Education, 13:1, 1-12, DOI: 10.1023/a: 1015171124982

Astalin, P. K. (2013). Qualitative research designs: A conceptual framework. *International journal of social science & interdisciplinary research*, *2*(1), 118-124.

Auerbach, C.F., & Silverstein, L. B. (2003). Qualitative data: An introduction to coding and analysis (Vol. 21). NYU press.

Babbie, E. & Mouton, J. (2010). The practice of social research. 10th ed. Republic of South Africa [RSA], Cape Town: Oxford University Press Southern Africa.

Bagheri, M., & Zenouzagh, Z. M. (2021). Comparative study of the effect of face-to-face and computer mediated conversation modalities on student engagement: speaking skill in focus. *Asian-Pacific Journal of Second and Foreign Language Education*, *6*(1), 1-23.

Bakia, M., Shear, L., Toyama, Y., & Lasseter, A. (2012). Understanding the Implications of Online Learning for Educational Productivity. *Office of Educational Technology, US Department of Education*.

Bao, W. (2020). COVID-19 and online teaching in higher education: A case study of Peking University. *Human Behavior and Emerging Technologies*, *2*(2), 113-115.

Bernstein, B. (1971). Class, Codes and Control vol 1 London.

Blackie, M. A. (2014). Creating semantic waves: Using Legitimation Code Theory as a tool to aid the teaching of chemistry. *Chemistry Education Research and Practice*, *15*(4), 462-469.

Brigitte S (2017). Rigor or Reliability and Validity in Qualitative Research: Perspectives, Strategies, Reconceptualization, and Recommendations

Brown. R (2019). 13 Differences between online and face to face course. Retrieved from https://miamioh.edu/regionals/academics/elearning/ecampus-faculty-staff/eccoe-news/2019/01/differences-between-f2f-and-online.html.

Bušelić, M. (2012). Distance Learning–concepts and contributions. *Oeconomica Jadertina*, *2*(1), 23-34.

Byers, S. (PhD, 2018). An LCT Examination of Comprehension and Pedagogy in Middle Years English and Science, University of Wollongong, Australia

Clarence, S. & Mckenna, S. (2017). *Developing academic literacies through understanding the nature of disciplinary knowledge*. London Review of Education. 15. 38-49. 10.18546/LRE.15.1.04.

Clarence, S. L. (2013). Enabling cumulative knowledge-building through teaching: A Legitimation Code Theory analysis of pedagogic practice in law and political science (Doctoral dissertation, Rhodes University).

Cohen, L., Manion, L., & Morrison, K. 2007. Research methods in education. London: Routledge.

Cowley-Haselden, S. Building knowledge to ease troublesomeness: Affording theory knowledgeability through academic reading circles, Journal of University Teaching & Learning Practice, 17(2), 2020.

Cranwell, P. B., & Whiteside, K. L. (2020). Investigation into the semantic density and semantic gravity wave profile of teachers when discussing electrophilic aromatic substitution (SEAr). *Journal of chemical education*, *97*(10), 3540-3550.

Creswell, J.W. (2012). Education Research: Planning, conducting, and evaluating quantitative and qualitative research (4th Ed). USA, Pearson Education Inc.

Daniel, J. (2020). Education and the COVID-19 pandemic. *Prospects*, *49*(1), 91-96.

DoE. (2014). Curriculum and assessment policy statement (CAPS): Technical Sciences. Retrieved 30 March, 2021, from https://cms.fedsas.org.za/

Edwards, N. (2010). An analysis of the alignment of the Grade 12 Physical Sciences examination and the core curriculum in South Africa. *South African Journal of Education*. 30. 571-590. 10.15700/saje.v30n4a389.

Erlandson, David A.; Harris, Edward L.; Skipper, Barbara L. & Allen, Steve D. (1993). *Doing naturalistic inquiry: a guide to methods*. Newbury Park, CA: Sage.

Fagan, D. (PhD, 2020) Using ICTs as a Pedagogical Resource to Facilitate Epistemological Access in Science with Teacher Education Students, PhD thesis, University of the Western Cape, South Africa.

García-Carmona, A., & Criado, A. M. (2009). Introduction to semiconductor physics in secondary education: evaluation of a teaching sequence. International Journal of Science Education, 31(16), 2205–2245.

Golafshani, N. (2003). Understanding Reliability and Validity in Qualitative Research. *The Qualitative Report*, *8*(4), 597-606. https://doi.org/10.46743/2160-3715/2003.1870

Hassenburg, A. (2009). Distance education versus the traditional classroom. *Berkeley Scientific Journal*, *13*(1).

Hatch, J.A. (2002). Doing qualitative research in education settings. New York: SUNY Press. Chapter 1. Pp.11-20

Howard, S., & Maton, K. A. (2011). Theorising knowledge practices: a missing piece of the educational technology puzzle.

Hugo, W. (2014). Semantic density and semantic gravity. *Journal of Education*, *59*, 1-14.

Macken-Horarik, M. (2011). Building a knowledge structure for English: Reflections on the challenges of coherence, cumulative learning, portability and face validity. *Australian journal of education*, *55*(3), 197-213.

Maher, C., Hadfield, M., Hutchings, M., & de Eyto, A. (2018). Ensuring rigor in qualitative data analysis: A design research approach to coding combining NVivo with traditional material methods. *International Journal of Qualitative Methods*, *17*(1), 1609406918786362.

Martin, J. R., & Maton, K. (2017). Systemic functional linguistics and legitimation code theory on education: Rethinking field and knowledge structure. *Onomázein: Revista de lingüística, filología y traducción de la Pontificia Universidad Católica de Chile*, (1), 12-45.

Maton K., (2011), in Christie F. and Maton K. (ed.), Theories and things: the semantics of discipinarity in Disciplinarity: functional linguistic and sociological perspectives, London: Continuum, pp. 62–84.

Maton, K. (2009). Cumulative and segmented learning: Exploring the role of curriculum structures in knowledge-building. *British journal of sociology of education*, *30*(1), 43-57.

Maton, K. (2010) Segmentalism: The problem of building knowledge and creating knowers, in Frandji, D. & Vitale, P. (eds) Knowledge, Pedagogy & Society: International perspectives on *Basil Bernstein's sociology of education*.

Maton, K. (2013). Making semantic waves: A key to cumulative knowledge building. *Linguistics and education*, *24*(1), 8-22.

Maton, K. (2014) A TALL order?: Legitimation Code Theory for academic language and learning, Journal of Academic Language and Learning, 8(3): 34–48

Maton, K. 2013a. Knowledge and knowers. Towards a realist sociology of education. London: Routledge.

Maton, K. 2014a. Building powerful knowledge: The significance of semantic waves. In The future of knowledge and curriculum, ed. E. Rata and B. Barrett. London: Palgrave Macmillan.

Maton, K., & Doran, Y. J. (2017). Condensation: A translation device for revealing complexity of knowledge practices in discourse, part 2—clausing and sequencing. *Onomázein*, 77-110

Maton, K., and Moore, R. (2010). Social Realism, Knowledge and the Sociology of Education: Coalitions of the Mind.

McMillan, J. H. (2012). Educational Research: Fundamentals for the consumer. (6th Ed.). Cape Town: Pearson Education, Inc.

Mcnaught, L., K. Maton, J. R. Martin and E. Matruglio. 2013. Linguistics and Education 24: 50–63

Moloi, D. M. T. (2020). COVID-19 and the Digital Transformation of Education: What we are learning in South Africa. *Preprints*.

Mondol, M. S., & Mohiuddin, M. G. (2020). Confronting Covid-19 with a Paradigm Shift in Teaching and Learning: A Study on Online Classes. *International Journal of Social, Political and Economic Research*, *7*(2), 231-247.

Msusa, N. (2019) Semantic waves: Writer performance ranges on the National Benchmark Tests (NBT) academic literacy test, Alternation, 26(2): 267–289.

Naumescu, A. K. (2008). Science Teacher Competencies in a Knowledge Based Society. *Acta Didactica Napocensia*, *1*(1), 25-31.

Nkambule, T, & Mukeredzi, T. (2017). Pre-service teachers' professional learning experiences during rural teaching practice in Acornhoek, Mpumalanga Province. South African Journal of Education, 37(3), 1-9.

Patton, M. Q. (2002). Qualitative evaluation and research methods (3rd Ed). Thousand Oaks, CA: Sage Publications, Inc.

Pott, R. W., & Wolff, K. (2019). Using Legitimation Code Theory to Conceptualize Learning Opportunities in Fluid Mechanics. *Fluids*, *4*(4), 203.

Rocco, T. S., & Plakhotnik, M. S. (2009). Literature reviews, conceptual frameworks, and theoretical frameworks: Terms, functions, and distinctions. *Human Resource Development Review*, *8*(1), 120-130.

Rollnick, M. (2017). Learning about semiconductors for teaching—The role played by content knowledge in pedagogical content knowledge (PCK) development. *Research in Science Education*, *47*(4), 833-868.

Rollnick, M., Mundalamo, F., & Booth, S. (2013). Concept maps as expressions of teachers' meaning–making while beginning to teach semiconductors. *Research in Science Education*, *43*(4), 1435-1454.

SACE Final Draft PTS for Gazette as adopted by Council in November 2018

Scardamalia, M., & Bereiter, C. (1999). Schools as knowledge building organizations. In D. Keating & C. Hertzman (Eds.), Today's children, tomorrow's society: The developmental health and wealth of nations (pp. 274-289). New York: Guilford.

Scardamalia, M., & Bereiter, C. (2003). Knowledge building. In J.W. Guthrie (Ed.), Encyclopedia of education (2nd Ed., pp. 1370-1373). New York: Macmillan Reference, USA.

Scardamalia, M., & Bereiter, C. (2020). Knowledge Building: Theory, pedagogy, and technology. In K. Sawyer (Ed.), *Cambridge Handbook of the Learning Sciences.*

Schwandt, T. A. (2007). The Sage Dictionary of Qualitative Inquiry (Third ed.), Thousand Oaks, California: sage Publication, Inc.

Simonson, M., Zvacek, S. M., & Smaldino, S. (2019). Teaching and Learning at a Distance: Foundations of Distance Education 7th Edition.

Singh, B. V., Hugo, W., & Essack, S. (2013). What does Gravity, Density and Waves have to do with Pharmacy Education. *Unpublished PhD Thesis. University of Kwa-Zulu Natal*.

Tan, S. C. (2010). Developing 21st century teachers as a knowledge builder. International Journal for the Scholarship of Teaching and Learning, 4(2), 1-8.

UNESCO (2020). Education: From disruption to recovery. Retrieved 30 May 2020 from https://en.unesco.org/covid19/educationresponse

Walton, E & Rusznyak, L (2019) Cumulative knowledge-building for inclusive education in initial teacher education, European Journal of Teacher Education, 43:1, 18-37, DOI: 10.1080/02619768.2019.1686480

Wettergren, J. (2002). Understanding concepts needed for semiconductor physics. *European journal of engineering education*, *27*(1), 105-111.

Winberg, C. (Ed.), McKenna, S. (Ed.), Wilmot, K. (Ed.). (2021). Building Knowledge in Higher Education. London: Routledge, https://doi.org/10.4324/9781003028215

Xie, M. (2020) Enabling students' knowledge building in English classrooms in China: The role of teacher monologue, Text & Talk. https://doi.org/10.1515/text-2019-0126

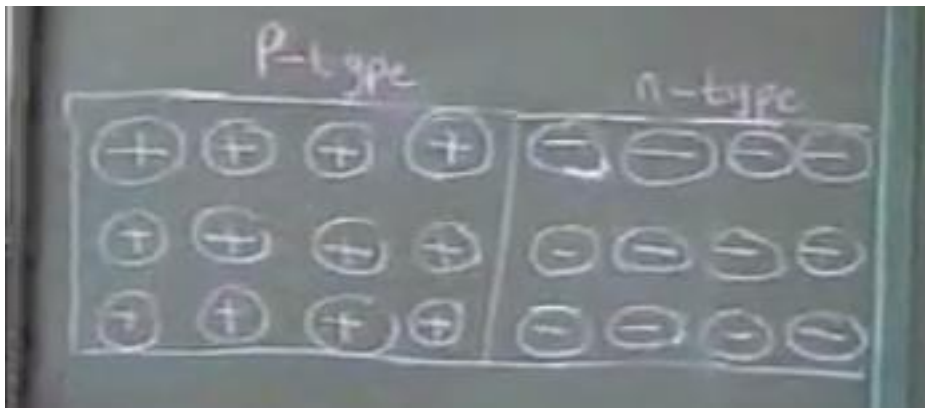
Yin, R. K. (2003). Case study research: Design and methods (3rd Ed.). Thousand Oaks, CA: Sage.

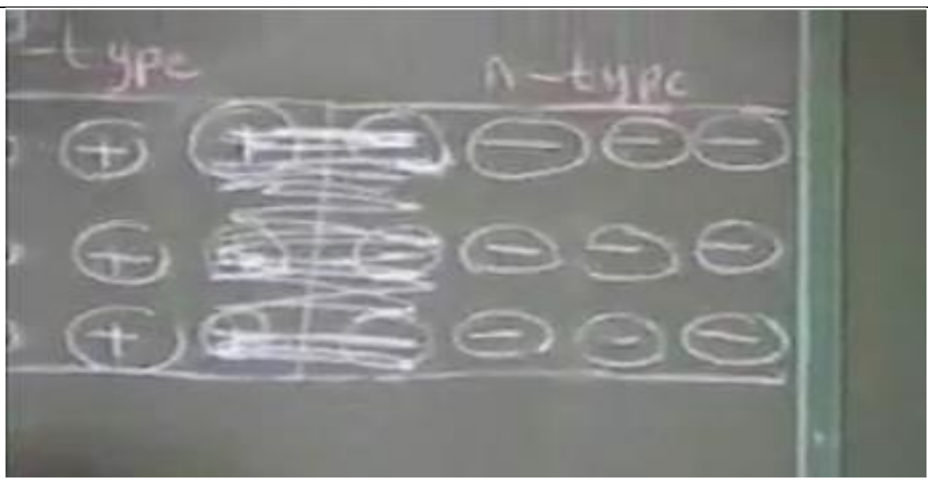
Zulu, S. I. (2018). Exploring Grade 10 rural physical science teachers’ perceptions and usage of everyday words in Acornhoek science classrooms, *Mpumalanga Province* (Masters Dissertation).

APPENDICES

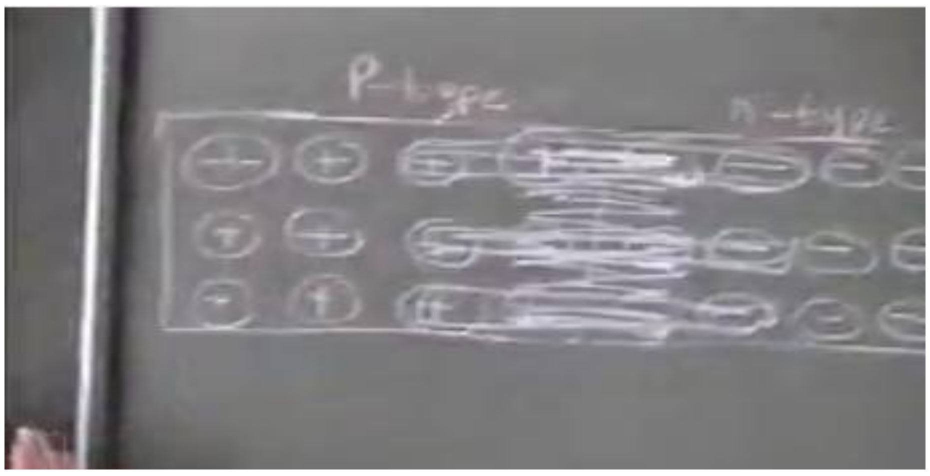
Appendix 1: Coded contact lesson transcription

Time in the lesson in minutes	Description of what was happening in the lesson	Coding (SG and SD)
0-10	Teacher: Remember previously when we were dealing with semiconductors. The last lesson was about the extrinsic semiconductor when we introduced doping as a method of increasing conductivity in semiconductors. Can you tell me exactly what is doping from the previous lesson? What did I say about doping? Yes? *Pointing to the learners.* Refilwe: Conductors that ……*inaudible*	SG− (Theoretical statement) SD+ (Teacher uses technical / subject terms, and explains what it means in an understandable way)
	Teacher: You include, we actually bring in the foreign element. You still remember the alien element? Silicon crystals if you still remember. So, we had some silicon crystal with electrons around it and we introduced a certain element which element can you remember? There was an alien- a foreign element that we used. Sipho: As Teacher: We used what? As which is what? Arsenic…and in which group is Arsenic if you look in your period table right now? It's in group? Learners: 15 Teacher: group 15 meaning it has how many electrons outside, the valence electrons? Learners: 5	SG+ (Hypothetical example) SD−
	Teacher: So, if we pair the four electrons around the Arsenic what we end up having is one free electron and because of this free electron that is able to move around, so we say it forms a certain type of semiconductor which we call it what? An n-type. What did we say about this n, what does n stand for?	SG− SD+
	Learners: Negative Teacher: It means there is an extra electron, so it forms an n-type and again in the same silicon structure we introduced another foreign element that we used. Which element was it? Learners: Boron Teacher: We used Boron! In which group is Boron? Group? Learners: 13	SG− SD+

	Teacher: So, the reason why we chose group 13 element is because it is going to have three valence electrons around Boron and it means there will be something that was formed, there was an empty space. What do we call that empty space? Learners: Hole Teacher: And what did I say the hole is? Alvin: It acts as……………...	SG− SD−
	Teacher: It acts I like that, or one can say it behaves as a what? As a positive charge. Okay? Teacher: For today let's assume for today lesson that we join the p-type and the n-type. Let's assume today we take the p-type and the n-type. Don't write anything. Remember the p-type are the holes, Okay? *Shows learners the diagram below.* 	SG+ (Hypothetical example)
	The reason why they are positive is because they act as positive charge. So now we put the holes for the p-type and we put what? Electrons for the n-type. But we just kind of included more electrons and more holes. So, we assume we put the p-type and the n-type together. From your experience about like charges and unlike charges what do you think would happen? Let's just talk about it. What do you think would happen here, when we have the p-type acting as the hole and the n-type which are the negative? What do you think can happen when you look at this?	SG+ (Hypothetical example) SD+
	Alvin: It can attract Teacher: It can attract! Remember unlike charges attract each other. In other words, we going to have electrons here quickly neutralizing the hole as more like a negative and what? (Referring to a diagram). Learners: Positive. Teacher: So, there will be attraction here and remember the one that is next to it, it will attract and this one also will attract. *Demonstrates this on the diagram below.*	SG+ (Hypothetical example) SD−

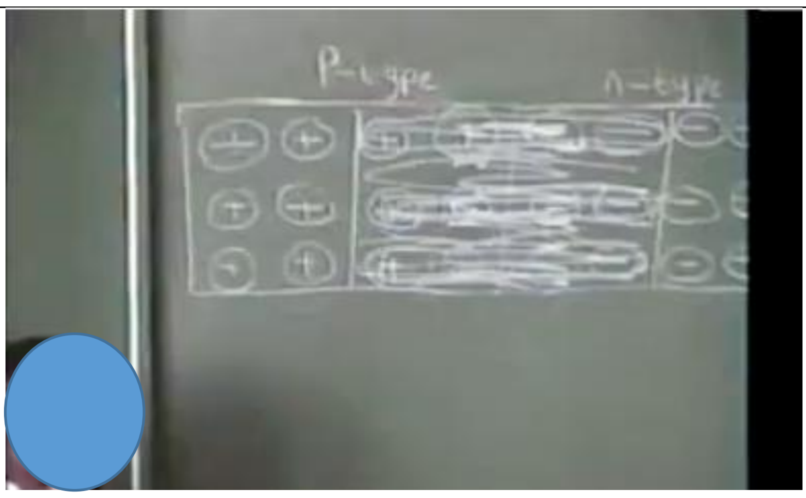
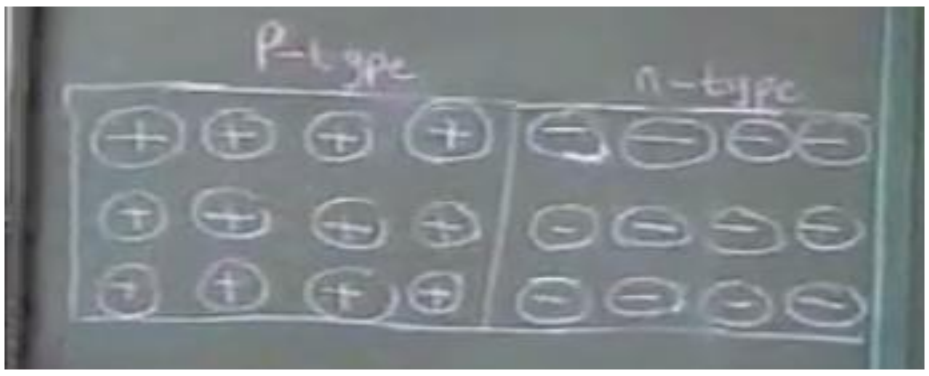
<table>
<tr>
<td></td>
<td>

Now, there is something that you need to know. There can also be neutralization for this and this one because they are not actually that far (Shows learners a diagram that further illustrates the charges from the far left and far right of each n-type neutralizing



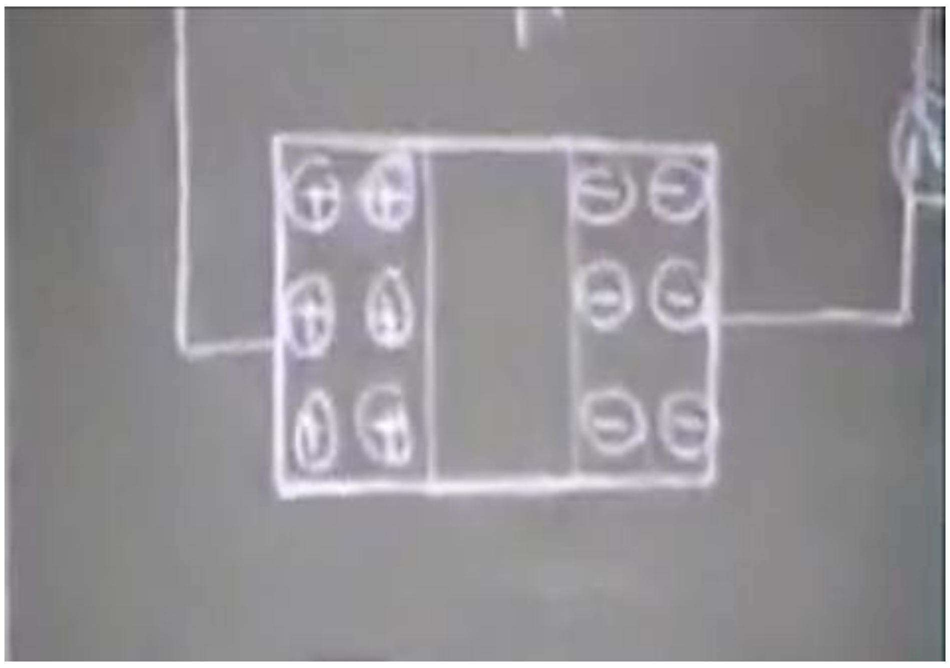
(((((So, if this one can also neutralize…. the positive can also neutralize the hole and the electron can also neutralize with the hole (Referring to the diagram above).
From our experience that like unlike charges attract, so because of that this can attract and the hole can neutralize with the electron, a hole can neutralize with even the ones that are in the second hole can also neutralize))))).</td>
<td>SG+ (Hypothetical example)
SD−

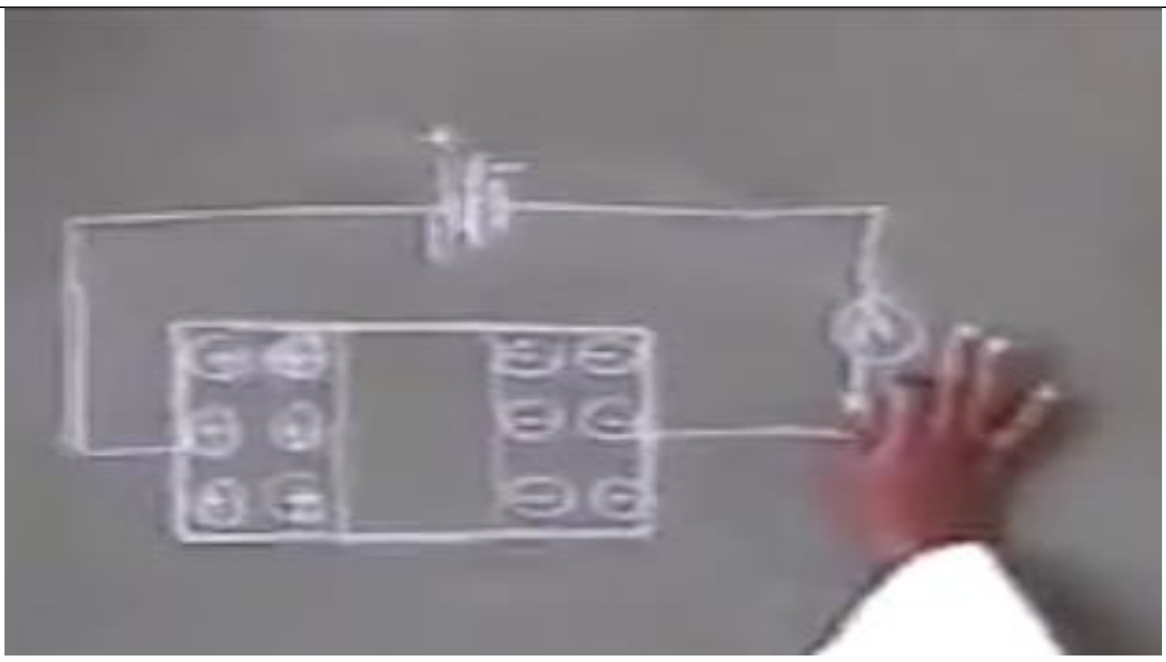
Still SG+
Now SD+</td>
</tr>
<tr>
<td></td>
<td>Teacher: But there is something you need to know. Now remember if you look at this electron now it’s really far from the hole. So, chances are because of this gap it’s almost impossible for electron to neutralize with the hole., because of the gap (Showing learners a diagram)</td>
<td>SG+
SD−</td>
</tr>
</table>

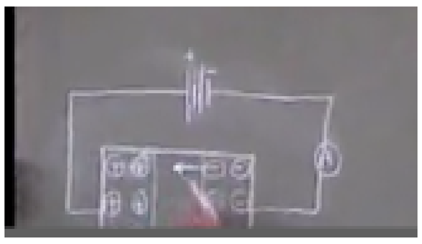
	 Remember from our band theory lesson we learnt something about gaps. The larger the gap…. The more difficult it is for the electron to move to the hole. So same applies to this one, after neutralization occurs so what happens is …it's difficult for the electron to neutralize the hole.	SG− (Theoretical statement) SD+
	If I can draw this diagram again, what is left now is that space. The space here is left with holes and we can put holes here and the electrons that are left, remember the excess electrons *(Referring to the diagram below)* So, we call this space here (Referring to a diagram) a depletion region. Why do we call this space a depletion region? It's because there are no charges. That is why we call it a depletion region because there are no more charges due to gap that was formed when holes and electrons were neutralized. So, the space that is formed here we call it a depletion region. The reason we call it that is because there are no charges. And now because it is no longer the same as this structure here *(Referring to this diagram below)* so we call this kind of a structure a p-n junction. Now it's more like a p and n are now together, they are now combined that is why we call it a p-n junction. 	SG+ SD++ New concept

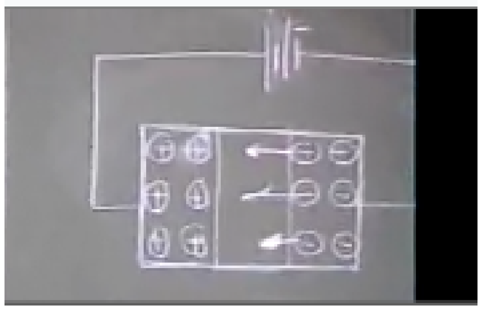
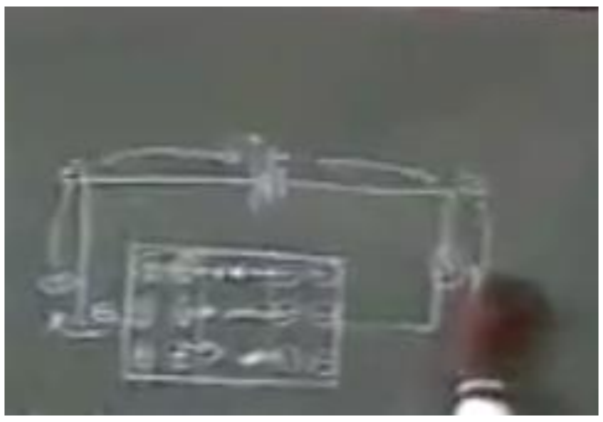
	Now it's more like a p and n are now together, they are now combined that is why we call it a p-n junction. And as you know that when we talking about semiconductors they are used widely in electronics appliances, isn't it? Electronics people do not really call it a p-n junction but they call it a diode. I don't know if it is for the first time some of you hear about a diode. What is a diode? Nelson: It is something that can convert that automatic current into direct current and is usually used in machines.	SG+ SD–
	Teacher: Yes, it's a very important component in electronics appliances and it acts the same as the p-n junction, don't forget that. It's just that they call it a diode. It does the same thing as the p-n junction, okay?	SG+ SD–
	So, we call it a diode and it's used widely by the electronic appliances and has the symbol, so the symbol of a diode is actually this one…. ***draws on the board.***  Where this is a positive and this is a negative. So, this is a symbol of a diode, if you look at the next diagram in the next activity you will realize that a diode has this kind of symbol where this one presents a positive and we sometimes call it a what? An anode. And the symbol of an anode is A. And this one a negative we sometimes call it a cathode; a symbol of a cathode is K. (*Referring to the diagram below).*	SG+ SD+++
	 But today in our lesson we will be using two types of diodes, okay I will be showing you the two types of diode. We will be using the first diode called the ordinary diode (*Shows learners the macroscopic representation of a diode)*. We are going see when we use it in a group.	SG++ (Direct experience/ example) SD+

	That grey part is a positive side and the black side is the anode side and another type of diode that we will be using today is called LED. I don't know if it's for the first time you hear about that. It's called LED, why is called LED? This is just the abbreviation *(writes the abbreviation on the chalk board)* Anyone who knows what is LED? Alex: Light emitting diode. Teacher: Yes, it's a light emitting diode. Why do we call it a light emitting diode? What's the reason behind that? Can you raise up your hand and tell me? Anele: I think it's because when the both charges come together that's when the light will glow. Teacher: Yes, it emits light. Excellent! The reason why we call it LED is because when it is connected it's actually showing a light that's why the symbol for LED makes use of the arrow to show that it means light. So, these are types of diodes and remember they act as p-n junction. Alright? *(Draws diagram on the board)* 	SG+ (Hypothetical example) SD−
10-20	Teacher: Now, let's assume when we take a p-n junction that is being formed. In other words, it's more like using a diode and we connect it to a battery. We all know a battery, right? And if we look at this structure here I already have a battery here, can you see that? *(Referring to the diagram below).*	SG+ (Hypothetical example) SD+

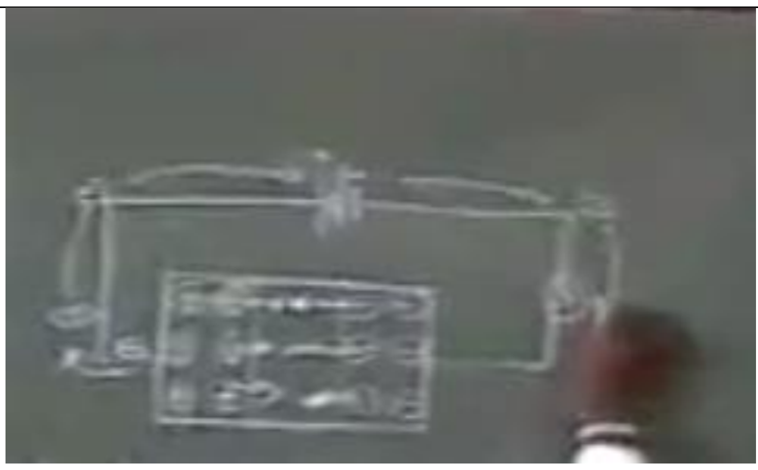
	 The positive terminal of the battery and the negative terminal of the battery *(Referring to the diagram above).*	
	 And here I put our p-n junction *(as depicted from the diagram above).* Are we listening? P-n junction is here and I just connected, let's assume this an ammeter connecter (*shows learners the diagram while pointing to the letter A on the circuit*.	SG+ (Hypothetical example) SD−

	 Remember the ammeter tells you whether there is current flowing, Okay? Now in this part of the circuit where you connect the p-n junction with the cell connector, meaning there is now something that is giving out energy, Okay?	SG− SD+
	In this kind of a circuit the positive terminal of the battery will……. remember positive to what? Positive the hole. What do we think would happen positive and positive? I am listening raise up your hand and speak loudly. Yes Khulekani? Khulekani: It will be opposite…. *INAUDIBLE* Teacher: Opposite what? What do you mean? Let's talk about positive side hole not concentrate on this one. Let's talk about this one? Referring to the circuit diagram. Yes Nasan? Nasan: They will repel. Teacher: They will repel, otherwise can you elaborate on that, what do you think? Nasan: They will join Teacher: What do you mean join? Nasan: They won't attract. Teacher: They won't attract? In other words, James? James: …...*inaudible* Teacher: Let's not talk about current, let's talk about the positive terminal of the battery and what is going to happen. Think of the positive terminal of the battery and the holes. Remember they are like charges. Repunzo? Repunzo: I think Mam it' s going to…... *Inaudible*	Building the learner code. Explanations are encouraged in learning science. Teacher explicitly guide learners in their thinking

	Teacher: Not exactly. Kutlwano you want to try? Kutlwano: Mam I think the electrons - (*teacher interjects*) Teacher: We talking positive terminals and the holes, I said don't talk about this. Kutlwano: The positive terminal will fill in the holes because they are like terms.	
	Teacher: Now it means the positive terminal of the battery will push the holes to the side because there is repulsion. Remember when we talk repulsion- remember this is giving out the positive charges.	SG− (Theoretical statement) SD+
	The positive terminal of the battery will repel the holes meaning it will push the holes to the side …and same applies to this side (*referring to the negative terminal*), negative terminal of the battery to negative terminal will repel the electrons. And what do you think is going to happen? They will move closer can you see that? *(Referring to the diagram below).* 	SG+ (Hypothetical example) SD+
	So, if they move closer in other words it means there will be movement of electrons, they will be pushed by the negative terminal of the battery, it will push electrons and push electrons. Remember electrons are the ones that are actually moving.	SG− SD+
	Remember when I asked Kutlwano to move and I said take those electrons, there is the first electron being removed and then she left an empty space and I said France must come and he left space so remember the actual things that are moving are electrons *(Teacher was talking about a demonstration that the class previously did).* Electrons now move due to the repulsion coming from the negative terminal of the battery and even the holes they will look as if they will be moving *(Referring to the diagram below*	SG++ (Direct experience) SD−

		
	They appear as if they are moving meaning? So, it means electrons are being pushed fast by the negative terminal of the battery. We are going to have movement of electrons this side. Electrons will be moving like this coming right around the circuit. They will be moving, in other words that will be conduction. ***(Referring to the diagram below)*** 	SG− SD−
	Do you still remember what conduction is? Kutlwano: Are the electrons moving? Teacher: They will be moving right around because they are being pushed fast like that (*demonstrating a circular motion using hands*)- as long as there is a battery there will be moving hence they will be pushed right around the whole circuit.	SG− SD−
	But the question is, what about the holes? Remember the holes appear as if they are moving. But I can't make the sign like the one that I made for the electrons because this shows that the electron is actually moving *(referring to the diagram above).* So, for the holes I use the conventional current sign because they don't actually move. But this sign shows that they look like they are also going to the opposite direction, hence conduction is the movement of the electrons and the charges moving to opposite directions. So, with electrons it's actually moving that's why I made a sign to show that they are actually moving *(refers to the diagram above).*	SD++ SG−

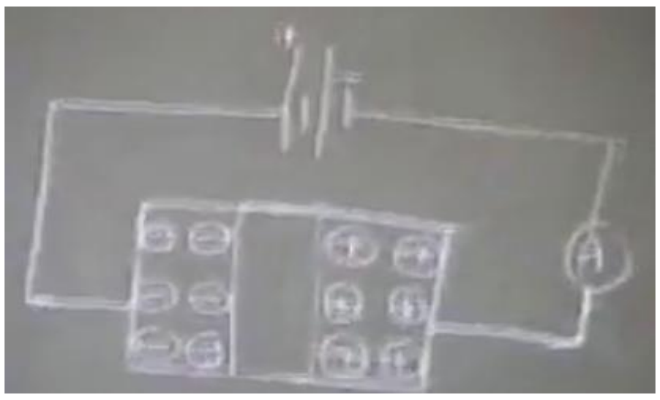
20-30	Teacher: Because there's a movement of electrons due to the movement of electrons therefore there will be conduction. Kutlwano: Can I ask? Teacher: Yes Kutlwano: Won't electrons be able to fill the space on the holes?	SG− SD+
	Teacher: Oh, now I get your question. Don't forget Kutlwano we took the excess electrons that couldn't able to neutralize each other. So, it's not like these electrons will be occupying the holes. Remember they were excess ones so they couldn't be able to neutralize each other. Did I answer you? Kutlwano: Yes Teacher: Good	SG− SD++
	Sihle: Is this actually like concerning metals or semiconductors? Teacher: Yes, just that here we are trying to go deeper remember we started with intrinsic semiconductors now we showing the components of such conductors. We still under conduction just basic conduction but remember most electronic components are semiconductors. Teacher: Now, this time of the circuit where we've got conduction taking place we call it a forward bias. So, we call it a forward-bias the reason why is called forward bias is because there is conduction. Meaning if I can repeat quickly *(Referring to the diagram below)*	SG+ SD+



The electrical terminals of the battery will push the electrons meaning this gap will get smaller and smaller until it’s been completely closed, offering a chance for electrons to go due to more electrons coming out of the battery. Same applies to the positive terminal of the battery it will push the holes. One thing I want you to remember is that it's not like they're moving they look like they're moving, so we call it a forward bias.

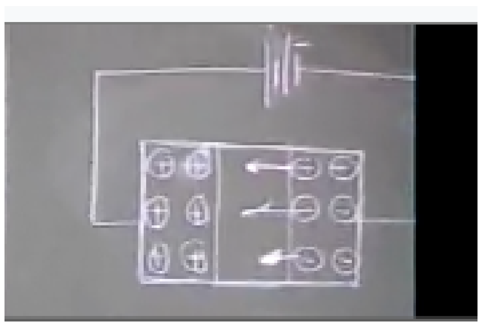
SG+

Teacher: Now, if we look at the next circuit diagram



On this side I still have my negative terminal *(Teacher is making a comparison between the two circuits drawn on the board – (shown below).*

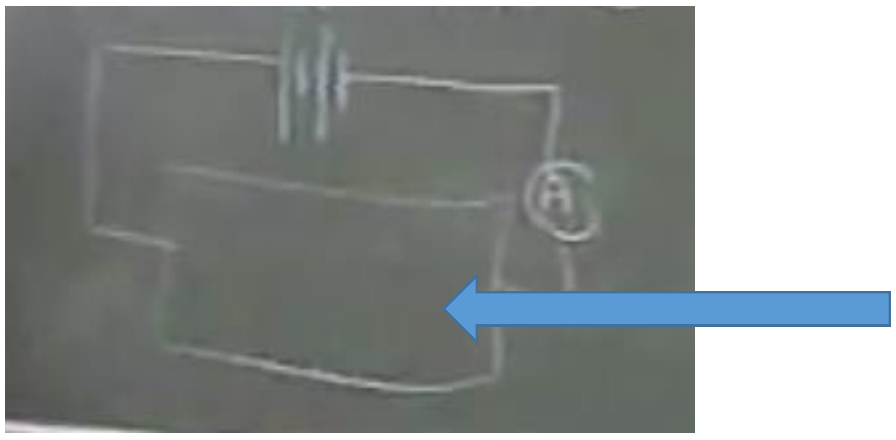
SG+
SD−

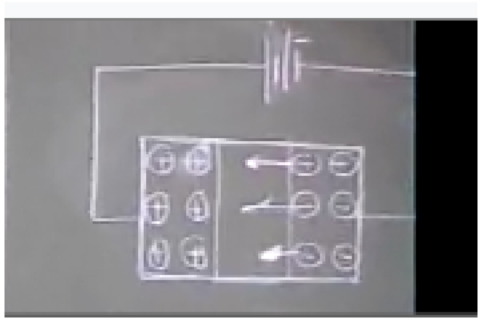


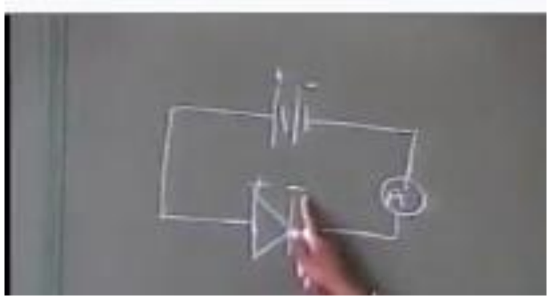
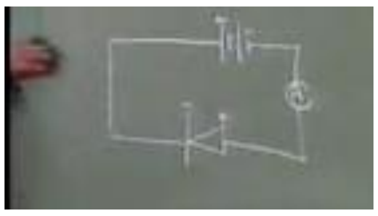
But what I did is that I took the excess holes and electrons. Are you with me? It's just that in this case there's a minor difference, what did I do in this case? Yes?

Vuyani: The difference is the holes.

Teacher: I put the holes on the right and the electrons on the left the reason we will see later. Now based on what I have explained here (*referring to the previous diagrams*) who can

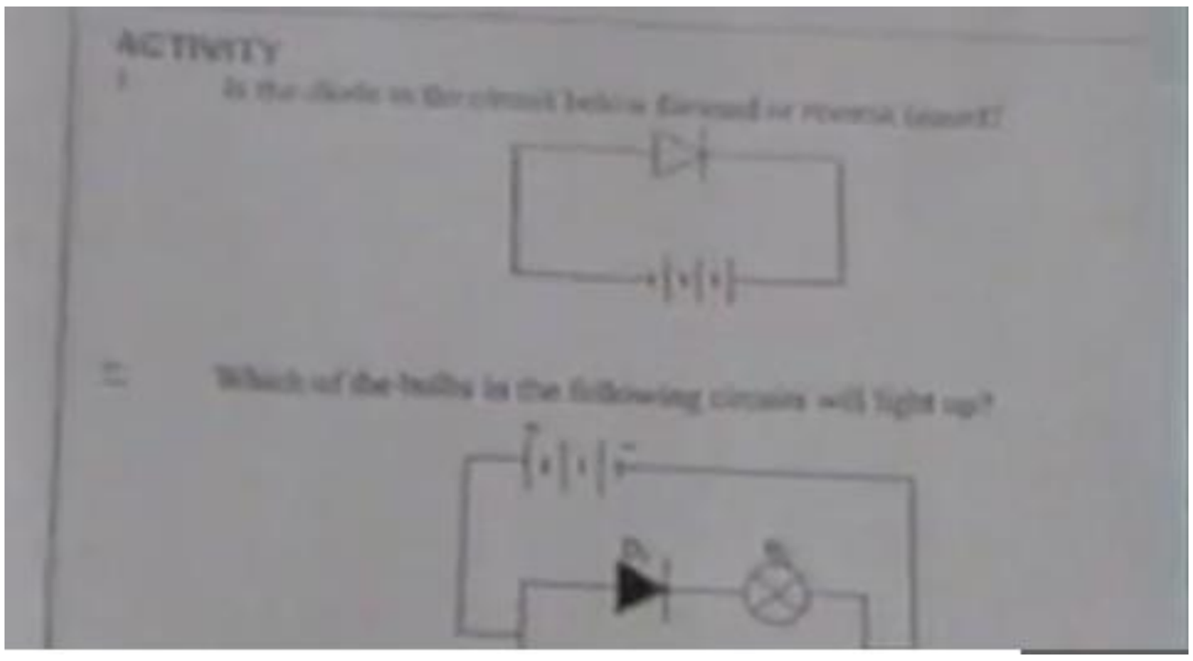
	try to tell us what you think is going to happen here (The t*eacher is referring to the diagram below)*  Raise up your hand and try to talk. Teacher: Based on what I have explained earlier on the forward bias circuit. What do you think on that side would happen? Remember the only difference is I put the holes on the right and the electrons on the left. Let us assume the gap is equal. Senzi: I think the electricity will conduct. Teacher: Okay I hear that. *Points to another learner.* Yes Vuyani?	SG+
	Vuyani: I think the gap is going to be huge. Teacher: Good! The gap is going to be huge. Excellent. Why you saying the gap going to be huge? Vuyani: Because the positive terminal of the battery will attract……... *(Teacher interjects)* Teacher: The positive terminal of the battery will definitely attract the electrons -opposite charges or unlike charges attract. So, the positive will attract all the electrons pulling them towards it and obviously the negative terminal of the battery will also attract the holes- it's unlike charges. The holes are acting as positive.	SG− SD+
	So, if I had to redraw it really quickly we going to have a larger region - a larger depletion region (*diagram shown below)*  Region of depletion shown above.	SG+

	Teacher: With all the electrons being taken by the positive terminal of the battery and with all the holes being attracted, there is no electrons that are moving in the circuit. Unlike this one *(Referring to the previous diagrams as shown below*)  Since there won't be movement of electrons we say this is not a forward bias but is reverse bias. The reason why we say its reverse bias is because there won't be any conduction.	SG+ SD−
	Another thing that is ……. the larger the gap, even if we can assume we've got more of them the fact is there are going to be attracted, the gap keeps on becoming wider (opening)so there are no way electrons will be able to move to that side and conduct, hence we call it a reverse bias. Any questions there? Jay? Jay: Nothing	New concept SG− SD+
30-40	Teacher: Anything that you want to know about that? Who can tell me? When will this stop? The positive and negative terminal will keep on attracting the holes until when? What do you think? Until the battery is dead - flat. As long as there is more, the battery is strong enough it can go forever and keep on attracting them. There is no way, it's like you trying to jump and someone is pulling you, they keep on pulling you and pulling you, further and further away from the region (at *this point in time the teacher is demonstrating the pull effect on the learners)*. Same applies to the holes (Referring *to the positive terminal*) so the larger the region, okay?	SG++ (Direct experience) SD−
	All learners: Yes Teacher: Now one more thing. Let's assume instead of the p-n junction that we see here we use a symbol that they use in electronics which is a diode. (Draws *diagram on the chalkboard as shown below)*	SG+ SD++

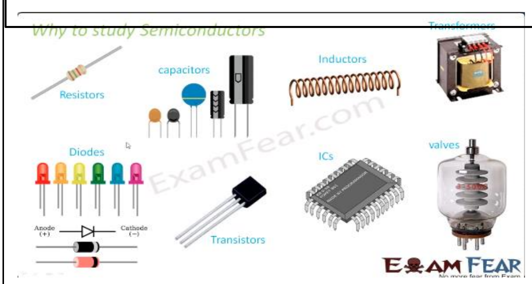
	  Teacher: What you see here is still a battery so our holes are positive electrons and negative are negative *(explaining while referring to the diagram above*). This is the forward bias but using a diode. Positive to positive they will be repulsion they end up getting closer closing the region so electrons can be able to cross. So, this is forward bias. Now, for the second one (*Referring to the diagram below)*  We can also have reverse bias using a diode and, in this case, what are we going to have? So, we going to have a what? A positive and a negative *(Showing learners the diagram above).*	SG+ SD++
	In this case positive terminal of the battery will attract the negative terminal. In this way it pulls it away and this side as well *(negative and positive pulls it away) (referring to the positive and negative terminal of the battery and the diode)* - hence there won't be conduction therefore this is a reverse bias.	SG− SD+
	Now there's a small activity that I want you to do as a group. You know your group members I'm going to start with this one, for every group I am going to give you this little yellow thing, I know most of you know what this is. What do we call this? Leaners: Multi-meter Teacher: A multi-meter. What do we do with a multi-meter? Who can tell me? What is it for? Pritchard? Pritchard: To test current Teacher: To test whether current flows. So, every group will have a multi-meter and it's already connected don't do anything and remember with a multi-meter you have to use it with	(Focus is on the practical) SG++ (Direct experience)

	an ordinary diode. This is because it doesn't show light, try to play with it and see if you can see any current flowing.	
	I'll come around and test what the group decided. Tell me the reverse bias and a forward bias using an ordinary diode. So, I'm going to leave and ordinary diode for each group. Another thing I'm going to give the battery to every group and the battery you are going to use it to test the forward bias and reverse bias, it means you will be using the LED light. Remember if the LED light up it means there is forward bias and if it doesn't light up it means it is reverse bias.	SG+ (Hypothetical example) SD−
	So, I'm going to drop the battery together with LED for each group and I'll be coming around to see if each group is able to get that. Remember we have to use our LED with a resistor and I'll put it there for you. What is the resistor for? Who can tell me? What's the reason for putting an LED with a resistor? Nelson: So that too much current can be controlled. Teacher: Yes, to control the current flow otherwise it will damage the LED. Which group didn't get the LED? Make sure you use them the way I have explained. The multi-meter and the ordinary diode. Remember the black side of the ordinary diode is positive. I will be coming around each group to see. Show me if it's reverse bias or forward bias.	SG+ (hypothetical example) SD−
40-50	Teacher: And again, if you look at the multi-meter, put it on the sign where there is diode. Move it around and tell me where you see the diode sign. Did you see the diode sign? Good let's see. *Throughout this point in time, the teacher is explaining how learners can conduct this small practical using the LED, resistor, battery and multi-meter to illustrate the reverse and forward bias. There are discussions within the group and the teachers is moving around asking learners questions. 'Is this a forward or reverse bias?' How do you know? Is there any light from the LED?* *The learners responded by stating that there is a reading on the multi-meter, therefore that is a forward bias and when there is no reading it is reverse bias. Leaners further stated that when the LED glows it shows that current is moving there that is a forward bias and when there is no light it is a reverse bias.* *The diagrams below show the illustration of the practical that learners were performing*	SG+++ (Personal experience) Learners are working with the Diode, multi-meter and see how it works in reverse and forward bias. SD− In this section the teacher is also shaping the knower gaze.

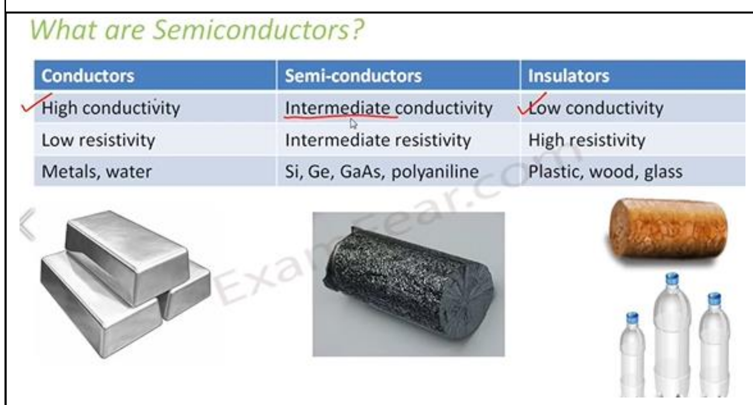
	 	
50-60	*A class discussion emerged as soon as learners were done with the small practical activity.* Teacher: How was your experience using the diodes and seeing the reverse and the forward bias? Nelson: It was interesting to see current flowing. Teacher: Good Teacher: Can someone from the next group share their experience? Kutlwano: Sometimes it is scary because you are thinking what if I break these things. Teacher: Okay. That is the only problem. Can anyone from this group tell us their experience? Sam: We had a fault with our LED because it did not light up, we think the problem could have been the battery. We are hoping that we redo and see how it actually works out. Teacher: Can another group send their materials so that this group can quickly see the forward bias and reverse bias using the LED. Let us give them a chance before we move on. *The group is given a chance to re-do the practical and their LED lit up*. Learners in the group: That is the forward bias. The other way around it means the LED won't light up so that will be the reverse bias. Teacher: Can others share how their experiences was?	SG+++ (personal experience) The teacher is also shaping the knower gaze. Speaking to how learners can work effectively with scientific understanding (science work involves random trials till the required outcome is obtained.)

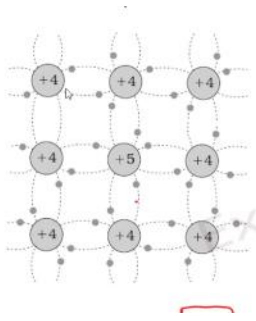
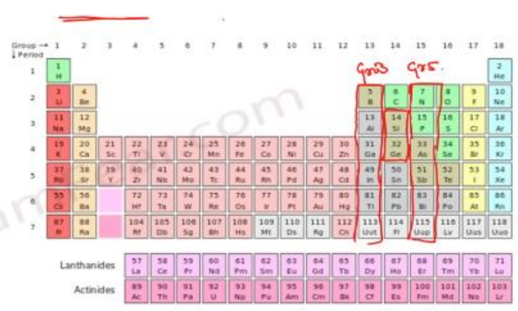
	Prince: When we used the LED there was light showing that there is conduction. Teacher: Is that reverse or forward bias? Sipho: Forward. Teacher: What can you say about the multi-meter? Forward bias in the multi-meter? Learner: There was a reading for the reverse bias. Teacher: Let's redo the practical to see if you are telling us the truth. *Learners redo the practical and the teacher helps them to move towards a correct understanding.* Teacher: See it means your group didn't do it right. Now listen class, the next activity is coming and we moving back to our positions. This will be a small activity for about ten minutes on your own. Okay?	SG− SD−
	See in reverse bias our LED will not glow up and the multi-meter will not show any reading because there is no conduction. Remember conduction is the movement of electrons, this means that in reverse bias electrons are not able move as I explained earlier. But in forward bias our LED glows up and the multi-meter shows a reading because there is conduction. Learners are given an activity and the activity is explained as the teacher reads the questions for the learners before commencing with the individual write up. The diagram below shows a picture of the activity given to learners. 	SD++

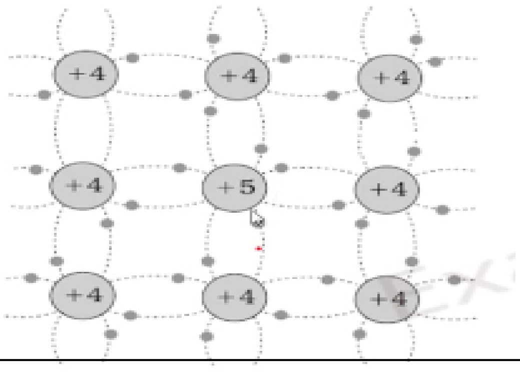
Appendix 2: Coded distance lesson transcription

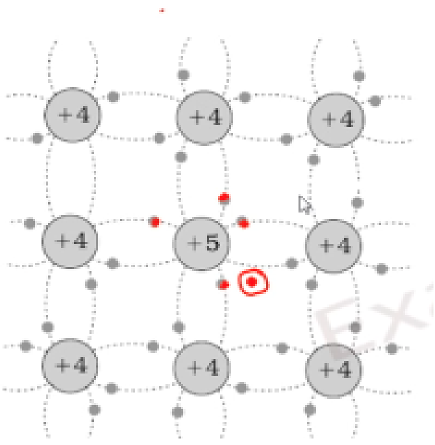
Time in the lesson (minutes)	Description of what is happening in the lesson	Coding SG and SD
0-10.00	Objects which you see around yourself, all objects like your laptop, your computer, a transistor, your microwave, your refrigerator, your cameras, video recorders, your calculators, batteries. There are so many things which you see around yourself and all of these have application of semiconductors. 	SG++ (Direct experience)
	Semiconductors are used in each of them in some or the other way. So, you can't use something that you really do not need in your life, I am sure all of you must be using such things. There is more laptops, computers, and cell-phones they have become so common these days. So, you understand, before you begin learning about something new you should always know what is the purpose behind learning that only then you will get that and go ahead with it. Since semiconductors have got so much of applications so it is worth enough to study in detail about semiconductors. Not long back we have studied about electric circuits, we studied about resistors, capacitors, inductors, transformers. We have seen all these things, we have seen such kind of applications, we have seen AC generators, DC generator, DC motor we have studied about quiet a lot of things.	SG++ (Direct experience)
	Try work something like this, if you look at any circuit, for an example if you try to open the CP of your computer, what do you see inside? So many circuits, right? It's like a small board with so many resistors, capacitors, inductors, all these things. Behind this you also get to see certain things like diodes. I am sure if you have observed any circuit closely you would have seen all these things. You will get to see diodes, transistors, you will see IC's. What is IC's? It's like an entire circuit which is made of a very small chip, it's very small. You get to see valves. *See picture below.*	SG+ (Hypothetical example) SD+ (Subject terms explained in understandable way)
	 So now you see different kinds of these things as well, so these are nothing but applications of semiconductors. So, semiconductors are a group of substances which have got some unique characteristics of its own and which can be made useful in various electronic applications and that is why we study the concept of semiconductors, since the concept of semiconductors is vast, so we study semiconductors almost as a different branch of physics. If you go for higher studies in physics, you will have your solid-state physics so that solid state physics is nothing, but it will talk only about such things. Right? So, this semiconductor is a very vast subject to discuss, however here for us, for your curriculum, we will just scratch the basics of semiconductors. Once you are dealing with the basics you will have no issue at	SG+ (Hypothetical situation) SD − (Concepts or words from the subject are used to convey meaning in straightforward ways that a non-subject specialist could understand

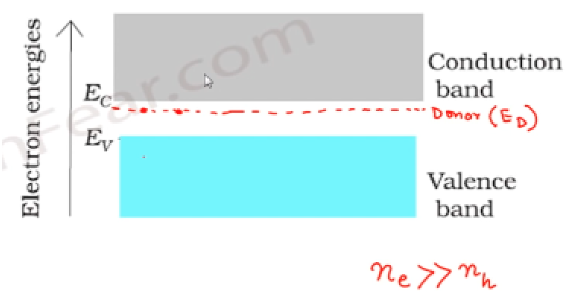
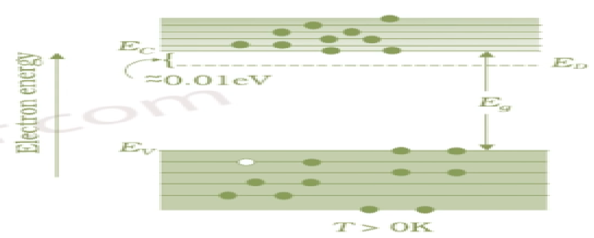
	understanding things at higher level. So please pay good attention to this lesson and try to understand the basic concept of what semiconductors are and how they work. So now you understood why we are going to study this lesson.	
	So now let us quickly talk about how semiconductors came into picture. People were always more interested to make use of controlled flow of electrons. All of you know that flow of electrons constitutes nothing but electric current. So electric current is something which is extremely important to us. An electric current was put into several hypothesis, but electric current should be in a controlled manner because if huge amount of current pass through a circuit it can damage the circuit.	SG− (Theoretical statement) SD+ (Teacher uses subject terms, and explains what it means in an understandable way)
	It can damage the components present in a circuit. Controlled flow of current was extremely important when you try to put current into practical purposes, right? Safety!! Only here we see that valves were used for this purpose. What were valves actually? Valves were nothing but an electronic component or you can say it was a device -in fact, you can say it was the only device during that time which allowed unidirectional flow of current that means which allowed current to flow in one direction.	SG− (Theoretical statement) SD+ (Teacher uses subject terms, and explains what it means in an understandable way)
	So, when I am talking about controlled flow of current, I am talking about the current which is flowing in a controlled manner in one particular direction. Valves was the only device which enabled this unidirectional flow of current but later it was found that when semiconductors were gradually introduced, and when the properties of semiconductors were gradually studied and then it was found that Semiconductors had more advantage, and they were good enough to replace valves.	SG− (Theoretical statement) SD − (Concepts or words from the subject are used to convey meaning in straightforward ways that a non-subject specialist could understand)
	So, in LCD that liquid crystal display. What was LCD? LCD was nothing but the semi solid state semiconductors. So, the semi-solid-state semiconductor gradually replaced the valves. The television is a good example because all of you have seen how these LCD televisions took over the old television sets. Referring to the diagram below.  These days hardly of you buy those televisions because as I told you these valves, would have limited life, so they get destructive very quickly. So, the television will not have long life. So, people prefer to go for LCDs. This is all about how the semiconductors came into picture and not only that because it overcame the disadvantages of valves that came into picture, it also founded applications in many different fields.	SG++ (Direct experience/ teacher focuses on a real-world example) SD − (Concepts or words from the subject are used to convey meaning in straightforward ways that a non-subject specialist could understand)
10-20	Now let us come to the main topic and start discussing the concepts in this lesson. In this topic we will study what are semiconductors because it is important to know what semiconductors are. Then we can study about its properties and characteristics. Semiconductors as the name suggests is something between conductor and insulator. Semi means partially – half conductor, half insulator. So, when I compare the semiconductor with conductors and insulators, what do we see? Conductors will have got high conductivity and insulators have low conductivity, but when I talk about semiconductors, they have intermediate conductivity. That means their conductivity is less than that of conductors but greater than that of insulators.	SG− (Theoretical statement) SD+ (Teacher uses subject terms, and explains what it means in an understandable way)

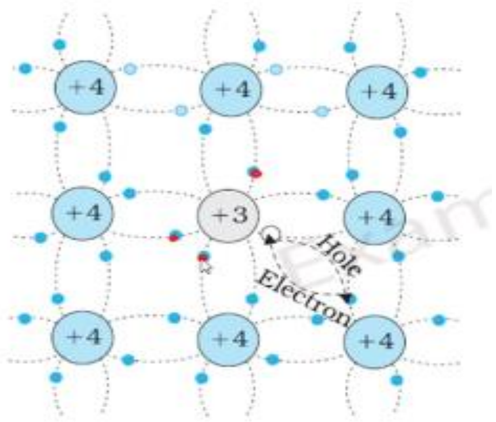
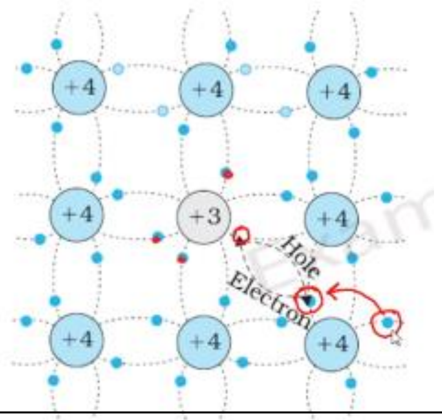
	So, conductivity is inversely proportional to resistivity, if the resistance is high the conduction will be low. Because resistance is nothing but the barrier to conduction. So, if conductors have high conductivity it is quite obvious that they have low resistivity. Insulators will have on the other hand, very high resistivity and semiconductors will have intermediate resistivity as well.	SG – (Theoretical statement) SD++ (Teacher makes connections between the concept and other ideas)
	 Now let us look at some of the examples. When we talk of conductors, we think we remember metals, mostly metals are conductors. Water is a good conductor of electricity. When I talk of insulators we think of plastic, food, glass all these things are insulators and bad conductors of electricity. When I talk of semiconductors, we have elements like silicon and germanium, which act as semiconductors. That means they can conduct electricity but not as good as conductors. Other than that, we also have compounds like gallium, arsenate, polyaniline which are on semiconductors. So now roughly you know what are semiconductor.	SG+ (Hypothetical example) SD++ (Teacher makes connections between the concept and other ideas)
	We will discuss extrinsic semiconductors in details. Extrinsic semiconductor will be something which is impure. What was the disadvantage? What disadvantage did you feel was there in the intrinsic semiconductor? The disadvantage was that until and unless you increase the temperature or until and unless you thermally excite the semiconductor it is same as insulator. In extrinsic semiconductor, small amount of a suitable impurity was added to it. What was the purpose of adding this impurity? So that it can conduct without supplying some external energy that sounds interesting right? Because if you use an extrinsic semiconductor it will always be conducting, without application of any external energy. Sounds good!	New concept SG– SD++
	This impurity is added in extremely small amount say a few parts per million (PPM), so this PPM is a kind of measuring unit which say parts per million. That means when you add something in extremely small amounts. I mean just imagine maybe you add one impurity out of 10 to the power six atoms. So, that means it is added in extremely small quantities. Impurity is added to increase the conductivity.	SG– (Theoretical statement) SD+ (Teacher uses subject terms, and explains what it means in an understandable way)
	As I told you because conductivity was the disadvantage with the intrinsic semiconductor. The process of deliberately adding impurity is known as doping. So, remember these new terminologies and the impurity is known as dopant. Right? Because we are knowingly adding impurity to a semiconductor, so this process is known as doping. Doping is done to increase the conductivity. Therefore, extrinsic semiconductor is also sometimes called as a doped semiconductor. That means basically an intrinsic semiconductor with addition of some impurity becomes an extrinsic semiconductor.	SG– (Theoretical statement) SD++ (Teacher makes connections between the concept and ideas)

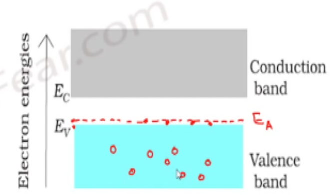
	Extrinsic semi-conductor is more useful because it has the conducting properties so this can be put into several practical applications. Now let us look at the impurities or what kind of impurities do we actually add to the semiconductor, so we will talk about the dopants here. That means the impurities which we add. A suitable dopant is one which has the same size as that of the semiconductor atom. Same size is a very crucial thing here. Right? Same size is a very crucial focus why? That is because as I mentioned before we are talking about crystal lattices. Your solid-state physics will talk about crystals because it only talks about substances which have periodic arrangement of atoms. Right?	
	So, now let us suppose if I want to add some impurity to a crystal, I should add an impurity in such a way that it should not affect the structure of the crystal as a whole. Now let us suppose if I am adding a dopant in a Silicon crystal so that Silicon crystal consists of thousands and thousands of Silicon (Si) atoms. Now let us suppose if I remove that Silicon (Si) Atom and place an Atom of extremely huge size there. So, will that huge atom fit into that space? First it will not fit into that space. Secondly if you forcefully try to fit it into that space it will distort the structure of the crystal. Similarly, if you place an extremely small Atom instead of a Silicon (Si) Atom what will happen? There will be a lot of empty space around it. Got it? So that means a suitable dopant is something which will have comparable size more or less it should be of the same size as that of the semiconductor Atom. That is a very important criteria to select a suitable to dopant.	SG+ (Hypothetical example) SD+ (Teacher uses subject terms, and explains what it means in an understandable way)
	Now if you look at the periodic table where does our semiconductor lie? Silicon (Si) and germanium (Ge) lie in group four of the periodic table. Right? So, if we want the dopant should have approximately the same size as that of these semiconductor atoms. The impurity should lie somewhere nearby, so that means there is one possibility that the impurity can lie in this group that is group three. There is another possibility that it can lie in group five because as far as atomic size is concerned as we go down the group the atomic size increases. Whereas as we move along the period from left to right, the atomic size does not decrease that much so it remains almost compatible. So that is why if you compare the atomic size of Boron (B) aluminum (Al) or Gallium (Ga) with Silicon (Si) and germanium (Ge) the difference will not be much. We can replace either with a group 3 impurity or group 5 impurity	SG+ (Hypothetical example) SD++ (Teacher makes connections between the concept and ideas)
	So now we have two possibilities, if we dope it with the group 5 impurity that extrinsic semiconductor is known as n-type semiconductor. And if we dope it with the Group 3 impurity it is known as a p-type semiconductor. That means extrinsic semiconductors is further divided into two types depending upon the dopant, which is used; depending upon what kind of impurity is added to the semiconductor. So, if group 5 impurity is added, it is called N type, if Group 3 impurity is added it is called as a P-type semiconductor. So, what we basically do this is how the crystal structure arrangement looks like right. ***See picture below.***	SG+ (Hypothetical example) SD++ (Teacher makes connections between the concept and other ideas)
	 	

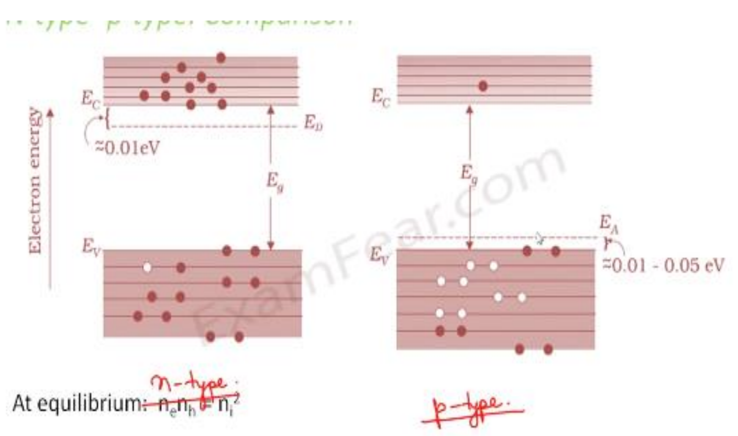
	Just like in the previous slides, it will have covalent bonding with the neighboring atoms. Then here as you see these are all Silicon atoms but here just one Silicon Atom has been replaced with a pentavalent atom that is a group 5 impurity. It can be anything it can be Phosphorus (P), arsenic (As), Antimony (Sb) so it is replaced with this atom. So, that is how we dope an extrinsic semiconductor, now can even see how does doping increase the conductivity, what changes take place when we add this impurity to the semi-conductor. ***See picture below.*** 	SG+ (Hypothetical example) SD++ (Teacher makes connections between the concept and other ideas)
	I have a group 5 impurity that is a pentavalent impurity. So, let us look at n-type semiconductor. As I mentioned the n-type semiconductor will have a group 5 impurity. So, group 5 impurity would be a pentavalent Atom whose valence would be five. Right? Let us take the examples of group 5 elements like As, P etc.	
		SG+ (Hypothetical example) SD+ (Teacher uses subject terms, and explains what it means in an understandable way)
20-30	So, let us look at the electronic configuration of phosphorus. The electronic configuration would be $1S^2\ 2S^2\ 2P^6\ 3S^2\ 3P^3$, which is my balance valence shell? Shell number 3. So, which has how many electrons? 5 valence electrons. So that means phosphorus has got 5 valence electrons. What was in case of Silicon (Si)? Si had four valence electrons. So now what will happen here I have included the phosphorus Atom? So now this was P, which has five electrons. Out of these five valence electrons, four have been involved in the covalent bond formation, like how Silicon used to do. But this time it has got one extra valence electron. So, what will this extra electron do? This extra electron is the one which is most loosely bound to the nucleus. Because when this extra electron looks at everybody else, he sees that all other 4 electrons are involved in the covalent bond, so he is the only one who is left out. So, if you apply a little bit of energy the first electron to come out would be this extra electron. Right? So, the amount of energy which is required by this extra electron is even lesser than what we needed in case of an intrinsic semiconductor ***See picture below.***	SG+ (Hypothetical example) SD+++ (Teacher uses condensed symbolic language to convey a concept)

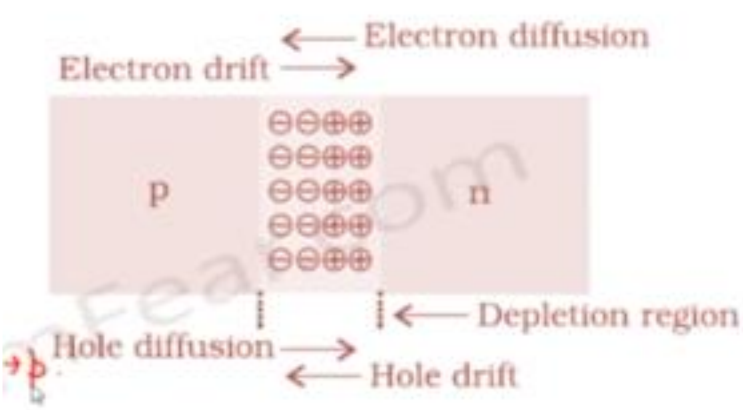
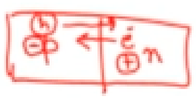
	 So, we do not even need to increase the temperature, at room temperature itself this extra electron will come out and these electrons will help in the conduction. So now you understand why we added this impurity, so that these impurities can keep some extra electrons which can help in conduction. Now this impurity that is this pentavalent impurity is known as donor impurity. By donor impurity this is because if you see, it has an extra electron and it is donating that electron for conduction purpose. Right? So, this impurity is known as a donor impurity. Now if you look at the semiconductor you see that you do not even need to raise the temperature, even at room temperature you have conduction electrons, you have the semiconductor conducting electricity	SG− (Theoretical statement) SD++ ((Teacher makes connections between the concept and other ideas)
	We saw the advantage of adding impurity, but at the same time the thermal generation will also take place. For example, now if you increase the temperature what will happen? These extra electrons will come out that is already there. Other than this extra electrons, the thermally generated electron holes will also be there, right, which we discussed in intrinsic semiconductors. So that means in that case both thermally generated electron and holes will be there as well as these extra electrons will also be there. Right? So, what do we observe?	SG+ (Hypothetical example) SD+ (Teacher uses subject terms, and explains what it means in an understandable way) SG− (Theoretical statement)
	(((((We observed that in this case the number of electrons is greater than the number of holes. You understand why so? It is because in the case of intrinsic semiconductor what was happening when you were applying thermal energy, some electrons were getting generated and simultaneously holes were also getting generated. That is why the number of electrons were equal to the number of holes. But in this case that process is there, other than that even at room temperature there are some extra electrons which are getting generated. This electron generation will not give rise to holes because these are extra electrons. Got it? Therefore, due to these electrons the number of electrons become greater than the number of holes. Right?)))))	SD+ (Teacher uses subject terms, and explains what it means in an understandable way) SG+ (Hypothetical example)
	Now if we look at the energy band diagram for an n-type semiconductor what do we see? We see that in case of an N-type semiconductor when we add a group 5 impurity there is an additional energy level which is created just below the conduction band. We call this as the donor energy level, which is denoted by E_D. Now the electrons which are present in this energy level they reach the conduction band at room temperature. So, the electrons which are present in this energy level they just need a very small amount of	SD++ ((Teacher makes connections between the concept and other ideas)

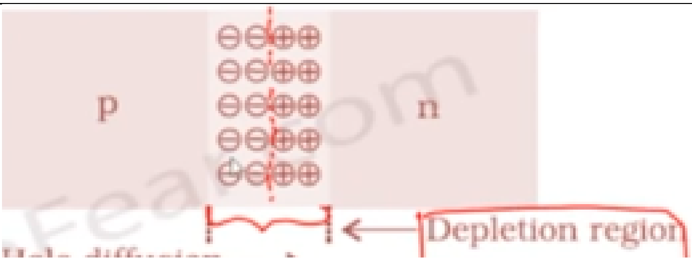
	energy. This much energy they manage to overcome even at room temperature and that is how they reach the conduction band, and this helps in conduction. ***See picture below.*** 	SG− (Theoretical statement)
	So, what were the key points to be noted in case of n-type semiconductors? What are the important points that we note about an n-type semiconductor? N-type semiconductor has number of electrons very greater than the number of holes. This is because of the extra electrons donated by the donor impurity Atom. So, the majority carriers in these cases are electrons, and the minority carriers as holes. This is a very important point to be noted, always remember that whenever we are talking about n-type the majority carriers are electrons and the minority carriers is holes. Right?	SD+ (Teacher uses technical terms, and explains what it means in an understandable ways) SG+ (Hypothetical example)
	So now you understand what the majority carriers means, most of the carriers are electrons because number of electrons is more. You can also see the energy band diagram on the screen that an additional energy level of the donor electron is created which is very near to the conduction band. So, a very small amount of energy even at room temperature can excite the electron from this additional energy level to the conduction band. ***See picture below.*** 	SD+ (Teacher uses technical terms, and explains what it means in an understandable ways) Teacher introduces a new concept
	Let us now discuss p-type semiconductor, so once we have discussed the n-type semiconductor it is easy to understand P-type semiconductor. In p-type semiconductor we have group 3 impurity, so a group 3 element would be a trivalent element as it will have the valence of 3 electrons.	SG−(Theoretical statement) SD+ (Teacher uses subject terms, and explains what it means in an understandable way) SG+ (Hypothetical example)
	Let us take the example of a Group 3 elements aluminum (Al). What would be the electronic configuration of Al? It will be $1S^2\ 2S^2\ 2P^6\ 3S^2\ 3S^2\ 3P^1$. So that means in the outer shell which is shell corresponding to n = 3 we have how many valence electrons? We have 3 valence electrons. So, what happens in this case, this is my Al impurity, so it has got 1, 2 and 3 valence electrons ***(making dots on the diagram as shown below).***	SD+++ (Teacher uses condensed symbolic language to convey a concept)

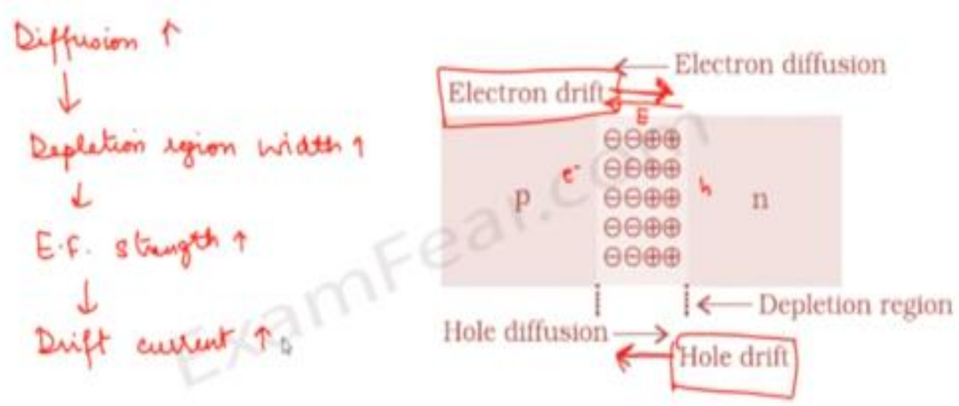
	 Now what happens? As soon as this Al Atom gains one electron the Al becomes a negative ion because it is taking one electron from outside. Before it was neutral but as soon as it takes one electron from outside that means it is taking an additional negative charge, so it becomes negatively charged. But since it is involved in the covalent bonding therefore it cannot move, even though it is a negative ion, but it cannot act as a charge carrier because it is immobile it is fixed at one place because of the bond formation on all sides.	SG− , SD+ SG+ (Hypothetical example)
	This Al Atom becomes a negative immobile ion. However, the holes which get created, for example this hole is created when the electron jump here. Again, in order to full fill this hole some electron jumps from here and the hole is created here. That means this hole is moving and one there, so this movement of the hole gives rise to a current in this case. ***See picture below***	SD+ (Teacher makes connections between the concept and other ideas)
30-40		
	That means in this case we have additional holes, like in the previous case the impurity gave us electrons, in this case the impurity is giving us a hole. In this case the impurity is known as an acceptor impurity because the impurity is accepting an electron from the neighboring atom. So, let me just denote it here (writing the screen) that is why this is known as acceptor impurity. This case also happens at room temperature, at room temperature these extra holes are generated. But when the temperature is increased thermal energy is provided, again the same process of electron hole pair generation take place. So, that means those electrons and holes are generated but in addition to that in this case its struggles are also there. So, number of holes in case of a p-type conductor is greater than that of the number of electrons.	SG− (Theoretical statement) SD++ (Teacher makes connections between the concept and other ideas)

	What are two things to be noted here? First the impurity is an acceptor impurity because it snatches electron from its neighboring atom, therefore the impurity becomes a negatively charged immobile ion. So here we have a negatively charged immobile ion, but the holes are getting generated. The movement of the holes gives rise to an additional current at room temperature and that is how semiconductors, conduct at room temperature. So, how will the energy band structure look like in this case? So, in this case we will again have an additional energy level, but this time it will be near the valence band and we denote it as E_A that is the acceptors energy level. So, who will reside on these energy levels? In this case what will happen here you have your electrons and holes? Now the electrons, the extra holes which are getting generated they will come to this acceptor energy level where the electrons will get excited very easily. And for electrons to excite from the E_V to E_A they need very small amount of energy, which they get at room temperature. So, electrons will come at this energy level EA as a result a lot of holes will be created in the valence band. The movement of these holes in the valence band will give rise to the additional current.  	SG – (Theoretical statement) SD+ (Teacher uses subject terms, and explains what it means in an understandable way) SG – (Theoretical statement) SD+
	Whenever I am talking about additional current, I am talking about the current which is in addition to the current which is thermally generated. So, right now I am talking about the room temperature current. When you are at room temperature there is no thermal generation of electron hole pairs. At that time these access holes in valence band gives rise to the current. Right? So, in p-type semiconductor number of holes is greater than the number of electrons, majority carriers in this case is holes and minority carriers in this case are electrons.	SG– (Theoretical statement) SD+ (Teacher uses subject terms, and explains what it means in an understandable way)
	So, if you look at energy band diagram in this case you can see that this is the acceptor energy level, since the electrons tend to move towards that accepting energy level. A lot of holes are created at the valence band, because of this movement of holes you get some additional current.	SG+ (Hypothetical example) SD+ (Teacher uses subject terms, and explains what it means in an understandable way)
	So far clear? So, till now we discussed about the types of semiconductors, extrinsic semiconductor, which is the impure form of semiconductor, where we add an impurity to increase the conductivity and the second one was the intrinsic semiconductor which was the pure semiconductor. Now you understand what semiconductors are, I think it is getting clearer now that semi-conductors are such objects which do not conduct electricity always. They conduct electricity when you do something that will make them conducts electricity, either you can add an impurity to it, or you increase the temperature and provide some additional energy. But if you give some effort from your side the semiconductor can conduct electricity.	SG– (Theoretical statement) SD– (Concepts or words from the subject are used to convey meaning in straightforward ways that a non-subject specialist could understand)

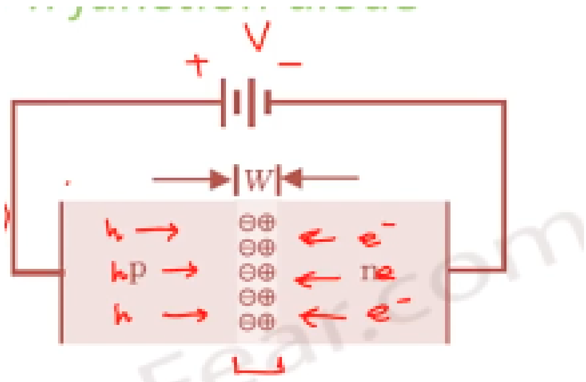
	So, let us quickly compare the energy band diagram of n-type and p-type semiconductor. In case of n-type semiconductors, we have additional electrons because the impurity in this case is a donor impurity which has extra electrons. So, because of this we have a donor energy level, so electrons can very easily jump from this level to the conduction band. Whereas in case of a p-type semiconductor we have impurity which is of acceptor type. That is, it accepts or snatches other electrons from neighboring atoms. As a result, holes get created and this movement of the holes or this generation of holes give rise to many holes in the valance band. Also, an additional acceptor energy level is created where it is very easy for the electrons to jump to this level. So here in this case in addition to the thermal generation of electron and hole you have additional holes, and this results in additional current. ***See picture below.*** 	SG+ (Hypothetical example) SD+ (Teacher uses subject terms, and explains what it means in an understandable way)
	Now what happens when it had been approximately found, in some experiments that were done and using some data, it was approximately found that at equilibrium number of electrons multiplied by number of holes gives square of intrinsic carrier concentration. However, this result is an approximate result, but it turns out to be true in most of the cases, that is number of electrons multiplied by the number of holes. In case of an extrinsic semiconductor the number of electrons multiplied by number of holes is equal to the intrinsic carrier concentrations square.	SG− (Theoretical statement) SD++ (Teacher makes connections between the concept and other ideas)
	We will now talk about a p-n junction formation. So, what is p-n junction? So gradually you can see we started with the very basics, now we will gradually get into complex things. However, this is not complex but now we understood what p-type semiconductor is, what n-type semiconductor is. Now what we will see is if we combine a p-type semiconductor with an n-type semiconductor what will happen. P-n junction will be formed that means there will be a junction which will be formed in between. Now let us look at what is a p-n junction? P-n junction is like the building block of semiconductor devices. So, you should understand that response of the P-N junction very clearly because this will be the same concept on this concept itself. You will build everything else when we talk of diodes, transistors and those were the things which I showed you in the introduction of this lesson. In understanding p-n junction you will be able to understand those things very easy. So, p-type and n-type semiconductor connected back-to-back gives rise to p-n junction.	Teacher introduces a new concept SG− (Theoretical statement) SD++ (Teacher makes connections between the concept and other ideas)
	Now what happens in this case? We know that in case of a p-type semiconductor the number of holes is very high. Whereas in case of an n-type semiconductor, the number of electrons is very high. So that means if you look at it here in this region, holes are too many. Whereas in this region they are too many electrons (Referring to a diagram). That means there is a difference in concentration in the two regions if we think of number of holes. Holes are very high in concentration in p region than in n region.	SG+ (Hypothetical example) SD+ (Teacher uses subject terms, and explains what it means in an understandable way)

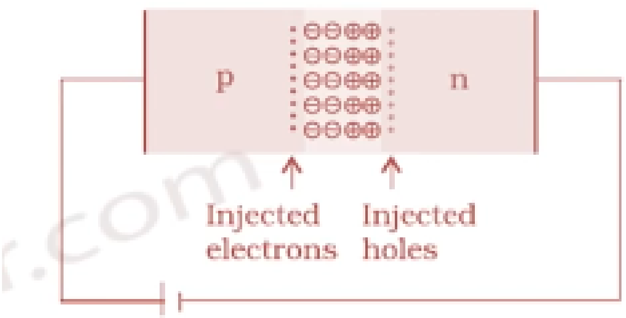
	((((((Now due to the difference in concentration in p region and n region what happens? Diffusion takes place. You know diffusion, right? What is diffusion? Diffusion means movement of particles from one region of higher concentration towards a region of lower concentration. So here diffusion takes place because p region has high concentration of holes and n region has low concentration of holes. So, what happens? Holes start moving. How will the holes diffuse? Holes will diffuse from which region to which region? From region of higher concentration of holes, so that is p region. So, it will move from p to n region. Whereas electrons will diffuse from region of higher concentration of electrons, that is from n to p region. So, this electron diffusion and holes diffusion will starts taking place. Right?  So, whenever you connect a p and n type semiconductor back-to-back. Electron diffusion and hole diffusion will start taking place. Now what will happen as these diffusion takes place? Now as a hole diffuse from p to n region as soon as a hole diffuse from p to n region, it leaves behind a negative immobile charge. Similarly, when an electron diffuses from n to p region it leaves behind a positive immobile charge.	SG− (Theoretical statement) SD++ (Teacher makes connections between the concept and other ideas)
40-50	Somewhat like this, let us suppose this is p region and this is n region. Now electrons from n region are moving towards p region. So, when the electron moves what is left behind? Some positive charge is left behind. Similarly, when a hole moves from p to n region, what is left behind? A negative charge ***See picture below***.  That means as this diffusion takes place some negative charges are left behind in the regions and some positive charges are left behind in n region and these charges are immobile, because they are bounded to the neighboring atoms so they cannot move. Right?	SG+ (Hypothetical example) SD+ (Teacher uses subject terms, and explains what it means in an understandable way)
	And this charge gives rise to a region for example, when electrons diffuse it leaves behind positive immobile charge. So, this positive immobile charge gives rise to positive space charge region on n-side. That means, let us suppose this was the separation between P and N type region. Now as the electrons move from N-region, the positive charges were left behind in the N region. So, these positive charges on the N side are known as the positive space charge region on N side. Similarly, as the holes diffuse, they leave behind negative immobile charge and these gives rise to negative space charge region on the P side. Now these positive space charge region and negative space charge region together is known as the depletion region. ***See picture below.***	SG −(Theoretical statement) SD++ (Teacher makes connections between the concept and other ideas)

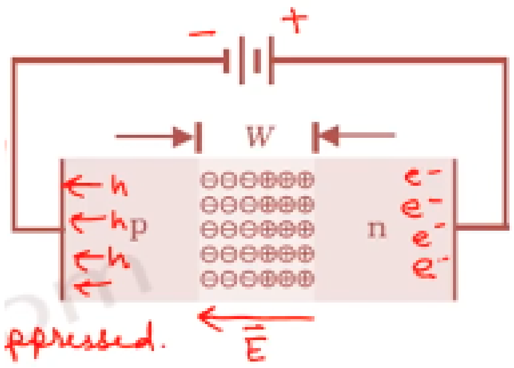
	 Why is this known as the depletion region? Because this region consists of all immobile charges which means they cannot conduct current. That is why it is called depletion region at least it is depleted of conduction. So, this depleted region is made up of the immobile positive and negative charges. Why does diffusion happen? Diffusion happen when p and n type semiconductors are connected to each other. As a result of diffusion what happens? Depletion region is formed. Right? Okay, so, what did we study? We talked about depletion region that is the space charge region on either side of the junction. Diffusion of majority charge carriers gives rise to depletion region. Another important thing to note here is, diffusion always happens with majority charge carriers. As I mentioned before diffusion will always take place from region of higher concentration to a region of lower concentration.	SG− (Theoretical statement) SD++ (Teacher makes connections between the concept and other ideas)
	So, if I am saying that electron diffusion is taking place, that means electron is moving from a region where electron concentration is higher, that means n region. N region is the majority carriers of electrons, so diffusion always takes place of majority charge carries. So, diffusion of this majority charge carriers give rise to depletion region. So, are you understanding what will happen if you connect a p and n type together? First of all, diffusion of majority charge carriers will start taking place. The majority charge carriers will start flowing across the junction, as a result at the junction you will have some positive charges and negative charges which together form a depletion region.	SG− ; SD++
	Now what will happen as a result of the depletion region, if you look at it, this depletion region also consists of positive charges on one side and negative charges on the other side (Referring to the diagram). As a result, an electric field will be established.	SG+; SD++
	For this depletion region there will be an electric field established and because of this electric field it will give rise to drift of minority charge carriers. That means this will be the direction of electric field, now what will happen? The negative charges which are present on the p side, those negative charges will start moving in a direction opposite to the direction of the electric field. That means the electrons which are present in the p region, these electrons will move in the direction opposite to this electric field so the electron drift will take place along this direction (**Referring to a diagram)**.	SG+; SD-
	Similarly, the holes which are present here (Referring **to the diagram**), they have positive charges so they will move along the direction of electric field so the hole drift will take place in this direction. So, what do we see? We see that diffusion gives rise to depletion region and depletion region gives rise to drift, drift of minority charge carriers. Fine is it clear to you? Because if you see the majority charge carriers are busy in diffusion, so all the majority charge carriers are moving across the junction. Now as this diffusion keep	SG+; SD+

	taking place, the rate of these depletion region keeps increasing, because as more and more diffusion takes place more and more immobile charges will be created.	
	Therefore, the depletion region will increase in width, now as the width of depletion region increases the strength of the electric field will also increase. As the strength of the electric field increases the drift of the minority charge carrier will also increase. Is that correct? Okay. So, let me note it down whatever I spoke. Diffusion happens whenever we connect to p and n-type semiconductor together because there is a difference in concentration of electrons and holes. So, diffusion gives rise to depletion region, so that depletion region width, as diffusion increases, depletion region width increases. As a result, the electric field strength also increases. Right? And as a result, the drift current also increases. 	SG−; SD++
	So, if you see when a p-n junction is formed. That means when you join a p and n- type semiconductors, there are two categories of currents involved, one is diffusion current, one drift current.	SG−; SD++
	Diffusion current is due to the majority charge carriers and drift current is due to the minority charge carries. Right? So, what do we see? Initially diffusion current is large and drift current is small. That is because initially there was no depletion region, as soon as you join a p and n- type, you will not get to depletion region. As the diffusion keeps taking place the depletion region will gradually form. So initially your drift current is very small because there is no depletion region. But the diffusion current is large because as soon as you join p and n type due to the difference in concentration electron diffusion and hole diffusion will start. But later what happens drift current keeps increasing and it reaches a stage when the drift current becomes equal to the diffusion current and at this stage, we see that a p-n junction is under equilibrium. So, p-n junction is under equilibrium, when the width of the depletion region is such that the electric field strength is just enough to overcome the diffusion current. Because here you can see (referring to the diagram) that the direction of diffusion current and drift current are opposite to each other. So, if the electric field strength increases in such a way that it reaches a point when this electron depth is exactly equal and opposite to the electron diffusion then what will happen? There will be no neckband, because diffusion current and drift current are being equal and opposite thus will cancel each other. So, you understood this concept of diffusion current and drift current.	SG−; SD+

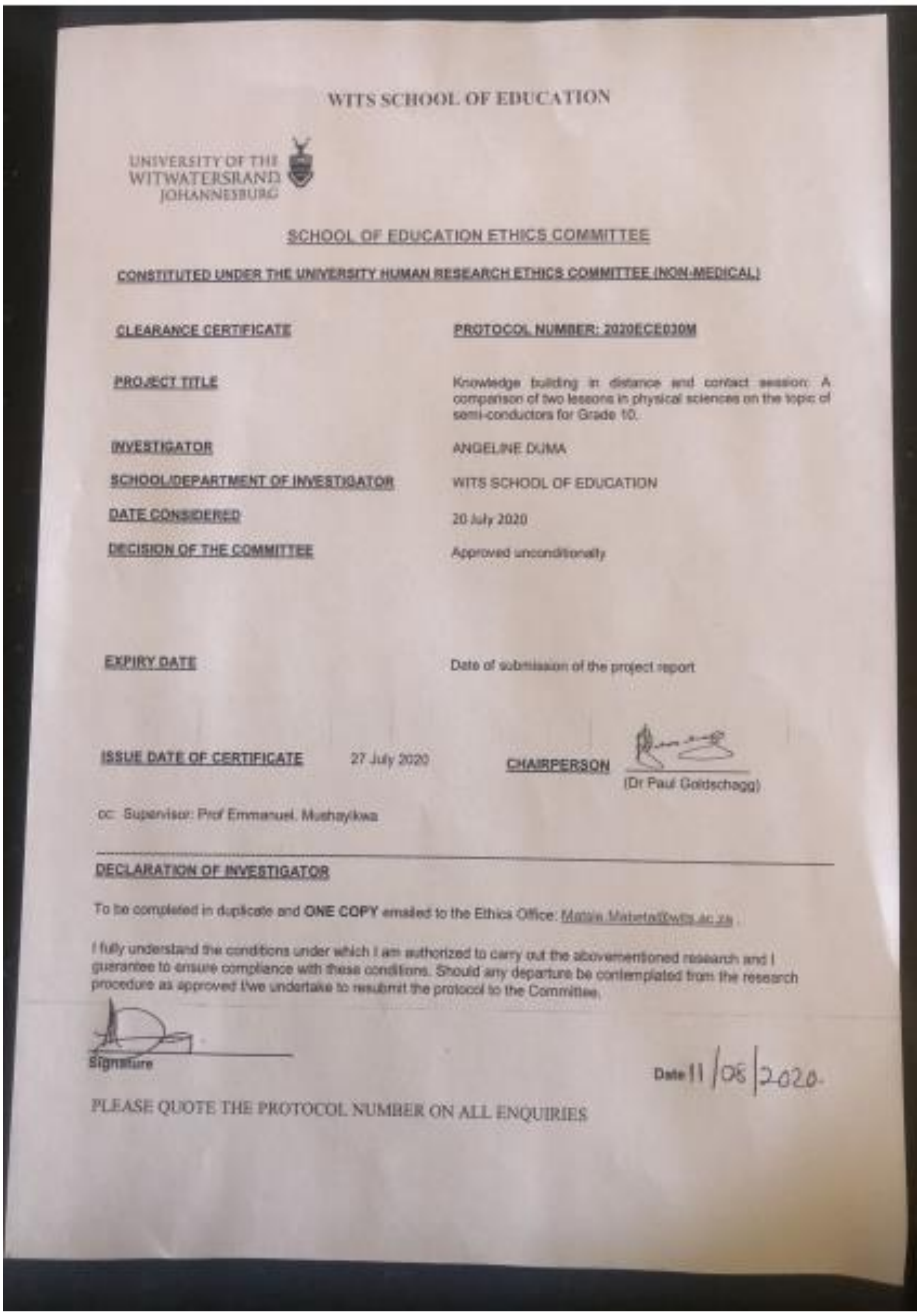
	((((((Now let us talk about that the p-n junction and equilibrium. When a p-n junction is at equilibrium what happens? Now at equilibrium what will happen the net current through the p-n junction will be equal to zero? That is because at equilibrium the electron diffusion current will be equal to the electron drift current. Similarly, the hole diffusion current will be equal to the hole drift current. Therefore, the net current will be equal to zero. However, there will be a potential difference between P and N. However, a potential difference exists between N and P. But why does the potential difference exist between N and P? That is because the electrons moved from N to P. Right? Right now, I am talking about the diffusion of electrons the majority charge carriers. So, the majority charge carriers move from N to P. So, what happened to N? N became positive. That means N region became positive. Right? Holes move from P to N. Since so many holes moved from P to N what happened? P side became negative. So that means N region is positive, so N is positive with respect to P. So, this results in a potential difference between N and P. Right? So, this potential difference restricts further flow of electrons from N to P. Is that right? Try to understand it in this way as soon as you join a P type and N type due to the difference in concentration diffusion starts. That is majority charge carriers start flowing from N region and P region. As a result of this depletion region is formed. As this diffusion continues the depletion region increases in width, at the same time that is one part. At the same time as diffusion continues the potential difference between N and P also increases. At a certain point, the width of the depletion risen is such. And the potential difference between N and P is such that it does not allow further diffusion of majority charge carries. At that point we say that the P-N junction is at equilibrium. So, this potential difference at equilibrium between P and N is known as barrier potential. So why do we call it barrier potential? Because this potential difference between n and p restrict further flow of majority charge carriers. So, it is the potential difference between n and p regions which restricts further flow of majority charge carriers across the junction. Barrier potential is also sometimes known as barrier height. Right?	New concept SG− ; SD+ and further to SD++
	So that means whenever we talk about this depletion regions, we talk about two things; one is the width of the depletion region and the other one is the barrier height. Barrier height is nothing but the potential difference between N region and P region. So, these two parameters actually decide when the diffusion will stop. Right? So, you understood the concept of a P-N junction? Please understand it very clearly because this is going to help you as you as we go ahead and start studying other things.	SG− ; SD++
50-60	Let us talk about the forward biasing of p-n junction diode in details. So, what happens when we forward bias a p-n junction diode? Let us suppose before biasing the diode when no external voltage was applied across the diode, there was a potential difference between the p side and the n side. That potential difference was known as the barrier potential, let me denote that as V_0 or we also called that as barrier height. So, let me call that as V_0.	New concept introduced SG−; SD+++
	Now let us suppose when we apply an external voltage, that is when the external voltage is at light, say the external voltage V. What will happen? This is positive side which is connected to p the negative side connected to n. Now when this external voltage V is applied this positive will repel the holes present in p, because p side will have more holes and holes are also positively charged. So, when it is connected to	SG+ (Hypothetical example) SD+

<table>
<tr><td></td><td>positive terminals it will get repelled from this site and it will start moving the holes will start moving towards the depletion region. (Referring to the diagram below)
Similarly, when we look at the n side the electrons will get repelled from the side due to this negative terminal and as a result the electrons of the inside will also start moving towards the depletion region. Now when the holes reach this depletion region it will combine, or it will recombine with some of these negative charges. Similarly, electrons will combine with some of these positive charges and as a result the width of the depletion region. This width will be reduced because some of these charges will get nullified because of these holes and these electrons. Right? So, the width will be reduced, and the barrier height will reduce that is because earlier the barrier height was V_0 before due to this movement and recombination of holes and electrons the potential difference between these two ends will also reduce.</td><td></td></tr>
<tr><td></td><td>So, when external voltage is applied what will happen? Depletion rate will reduce, and the barrier height will reduce. The barrier height will become? Earlier what was the barrier height it was V_0 now it will become $V_0 - V$ so it will be reduced by V. See picture below.

</td><td>SG− (Theoretical statement)
SD+++ (Teacher used condensed symbolic language to convey meaning)</td></tr>
<tr><td></td><td>Now if the applied voltage, if this value of V is very small in that case what will happen? The width will reduce a little bit, there will be a slight decrease in the depletion. Therefore, when the width reduces a little bit, little more electrons will be able to pass the junction, little more majority carriers will flow across the junction. As a result, the current will also increase a little bit. Now when the applied voltage is very large in that case what will happen? The decrease in the potential, the decrease in the depletion rate will be very large. The depletion will become very less and as a result the current will increase even more. That proves that as the external voltage is increased, the current will also increase. So forward biasing, encourages the majority carrier's flow. That means as you increase the forward biasing, as you increase the voltage, external voltage in case of forward biasing more and more majority carriers will flow across the junction, therefore the current will increase. So that means in case of forward biasing what is happening electrons are flowing from n region to p regions and holes are moving from p region to n region. So, it is encouraging the flow of majority carries. So, in another way what is happening? We can say that majority carriers flow is encouraged by forward biasing of the p-n junction diode.</td><td>Now what changes is SD+++ to SD+.</td></tr>
<tr><td></td><td>The same thing we can interpret it this way as I mentioned in the previous slide since electron is going from n to p and holes are moving from p to n that means what is happening, electrons are basically injected into p (Referring to the diagram below).
What does this mean? This means electrons are injected into p region. Similarly, holes are injected into n region. Now what are electrons in p region? Electrons are the minority carriers in the p region. So, we can say that minority carriers are injected into the region. This is also known as minority carried injection</td><td>SG+ (Hypothetical example)
SD++</td></tr>
</table>

	 So, what happens when we forward bias a p-n junction? When we forward bias a p-n junction diode it encourages the majority carrier flow. Now when the majority carriers flow from their region of high concentration towards the region of low concentration. It also in turn injects minority carriers into a junction, so that means forward biasing, causes majority carriers flow across the junction, minority carrier injection occurs. Both of these means the same right? Because majority carriers flow across the junction that means electron which is majority carrier in n it flows from n to p. So, this is called majority carrier flow, because electron is the majority carrier in n, so it is flowing from n to p.	SG−; SD+
	But if you look at it from point of view of p what is happening? For p electron is the minority carriers and electron is getting injected into p. That means minority carriers are getting injected into p region. This is what you can see here or in the p region you have the injected electrons and in the n region you have the injected holes ***(referring to the diagram above).***	SG+ (hypothetical example) SD+
	(((So, what is the total current in this case? The total current will be all diffusion current plus electron diffusion current because in this value forward bias as I told it encourages the majority carriers and majority carriers always diffuse. Diffusion is always related to majority carriers and drift is always related to minority carriers. In forward biasing they will always encourage the flow of majority carriers and majority carriers always diffuse across the junction. So, in this case total current is equal to whole diffusion current plus electron diffusion current))).	SG− ; SD++
	Now let us talk about the reverse biasing of the p-n junction. Now we will talk about reverse biasing on similar lines as we did for forward biasing. What happens in case of reverse biasing? In this case we connect the negative terminal the battery to the p side and positive terminal of the battery to the n side.	New concept SG− ; SD+
	So, in this case initially the potential difference between p and n was V_0 now when external voltage V is applied what happens to the barrier height? Earlier the barrier height was V_0. Now it becomes$V_0 + V$, that is because this negative will attract the holes which are present here.	SG−; SD+++
	As a result, more and more holes will come towards this end. Similarly, in this case also more and more electrons will come towards this end. In the previous case in forward biasing what was happening? These holes and electrons were coming towards the depletion region. As a result, it was decreasing the width of the depletion region. But in this case the opposite will happen as a result the depletion region will increase. Therefore, the flow of electrons from n to p and flow of holes from p to n will be suppressed (Referring to the diagram. As a result of this flow of electrons from n to p and flow of holes from p to n will be suppressed because in this case the barrier height has increased. So, it will not at all encourage the flow of majority charge carriers.	SG+; SD+

	But on the other hand, what will happen since the width is increasing the electric field strength will also increase. Now what is the direction of the electric field strength this is the direction of the electric field strength. Now electric field strength is such that the electrons on p- side will move towards n and the holes on n- side will move towards p. Now since depletion width is increasing, as a result of this the electric field will also increase and as a result of this drift occurs.  	SG− ; SD++
	What is drift? Drift is nothing but electrons from p- side, will move towards n- side and holes from n- side will move towards p-side. So, this drift of minority charge carriers will give rise to drift current. So that means applied voltage, does not play much role in deciding the drift current. For example, in case of forward biasing, we saw that as we increase or decrease the external applied voltage the amount of diffusion current also increased or decreased accordingly. But in this case the drift current is not dependent on the applied external voltage. The drift current is because of the width of the depletion region, so that drift current here depends on the concentration of minority carriers. Because more the number of minority carriers more would be the drift current because then more and more minority carriers will move across the Junction. So, we can say that drift current is not that much dependent on the applied voltage, instead it is dependent more on the concentration of minority charge carries. Now please students do not be confused because I am teaching one topic after another, there are related.	SG−; SD+

ETHICAL CLEARANCE



WITS SCHOOL OF EDUCATION

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

SCHOOL OF EDUCATION ETHICS COMMITTEE

CONSTITUTED UNDER THE UNIVERSITY HUMAN RESEARCH ETHICS COMMITTEE (NON-MEDICAL)

CLEARANCE CERTIFICATE	PROTOCOL NUMBER: 2020ECE030M
PROJECT TITLE	Knowledge building in distance and contact session: A comparison of two lessons in physical sciences on the topic of semi-conductors for Grade 10.
INVESTIGATOR	ANGELINE DUMA
SCHOOL/DEPARTMENT OF INVESTIGATOR	WITS SCHOOL OF EDUCATION
DATE CONSIDERED	20 July 2020
DECISION OF THE COMMITTEE	Approved unconditionally
EXPIRY DATE	Date of submission of the project report

ISSUE DATE OF CERTIFICATE 27 July 2020 CHAIRPERSON (Dr Paul Goldschagg)

cc: Supervisor: Prof Emmanuel. Mushayikwa

DECLARATION OF INVESTIGATOR

To be completed in duplicate and **ONE COPY** emailed to the Ethics Office: Matsie.Mabeta@wits.ac.za .

I fully understand the conditions under which I am authorized to carry out the abovementioned research and I guarantee to ensure compliance with these conditions. Should any departure be contemplated from the research procedure as approved I/we undertake to resubmit the protocol to the Committee.

Signature

Date 11/08/2020.

PLEASE QUOTE THE PROTOCOL NUMBER ON ALL ENQUIRIES