TRIGGERING PHYSICS LECTURERS' REFLECTIONS ON THE INSTRUCTIONAL AFFORDANCE OF THEIR USE OF REPRESENTATIONS: A DESIGN-BASED STUDY

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2014

TRIGGERING PHYSICS LECTURERS’ REFLECTIONS ON THE INSTRUCTIONAL AFFORDANCE OF THEIR USE OF REPRESENTATIONS: A DESIGN-BASED STUDY

By

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Submitted in fulfilment of the requirements for the degree of

Doctor of Philosophy: Education

to be awarded at the

Nelson Mandela Metropolitan University

Promoter: Prof Paul Webb

December 2014

ABSTRACT

There is growing awareness in the physics education research community about the importance of using representations in physics teaching and the need for lecturers to reflect on their practice. This research study adopted a design-based research approach in an attempt to design a reliable, valid and practically useful artefact (framework/strategy) that could be used to trigger introductory physics lecturers' reflections on their instructional use of representations. The artefact, which was instantiated with physics lecturers, comprised an observation protocol, an accompanying definitions key, a communication platform, and an instrument to assess the outcome (the levels of reflection). The video-data of lecturer practice were analysed using *a priori* codes to generate profiles of teaching practice. The resulting profiles were used to trigger individual video-stimulated reflection. The levels of reflection were assessed using a purpose-designed 'Expectations of Reflection' taxonomy. Thereafter a set of design guidelines and design principles were generated to guide further similar design-based educational studies. The process was validated via interview data but, while it was deemed a valid and reliable solution to the research problem, there were varying levels of perceived value of the artefact among the participating lecturers.

Key words: design principles; design-based research; physics education research; instructional use of physics representations, reflective practice; video-stimulated reflection

DECLARATION

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DECLARATION:

In accordance with Rule G4.6.3, I hereby declare that the above-mentioned thesis is my own work and that it has not previously been submitted for assessment to another University or for another qualification.

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DATE: 5 December 2014

ACKNOWLEDGEMENTS

I am most grateful to my heavenly Father for being the Source of strength to complete this study. He carried me through the stormy waters to waters of Peace and Acceptance.

This thesis would not have been possible without the efforts of my supervisor, Prof Paul Webb. Your unwavering enthusiasm kept my spirits up and encouraged me to develop and realise my research goals. You are a uniquely gifted researcher and educator because of your passion for research, and most of all, your genuine concern for others. You helped me through the turmoil of writing.

I would like to express my sincerest appreciation to the following people, who contributed to the completion of this study in various ways. I would like to acknowledge the cooperation and support of the Departments of Physics and Mechanical Engineering at the NMMU. Without their input this research would not have been possible. My sincerest thanks are due to the senior management of the Faculty of Education at NMMU who have enabled me to take a research sabbatical and the department of Research Capacity Development for financial support during the course of this journey. I would like to acknowledge the support I received from Mrs Carol Poisat and my fellow colleagues at the NMMU. Each one of your well-meant and sincere comments helped me through this process.

Lastly and most significantly, my heartfelt thanks are extended to my family, whose steadfast encouragement has helped me to persevere and succeed. I am particularly grateful to my husband, for his unwavering support and patience, his dedication to assist me in any possible way, and his acceptance of the life style change a Ph.D. study demands. Thank you. To my father and mother (Danie and Marie van Wyk) I wish to express my sincerest thanks

for your prayers, unconditional love, on-going support, and encouragement throughout my life.

This thesis is dedicated to my family and my extended van Wyk and Lombard families who are very dear to me. Dream big and do not give up on your dreams. Live every day to its fullest and to the glory of the Lord. May each one of you, in your own unique ways, have a positive influence in the world. I give you the promise of the Lord to accompany you on this journey.

Jaremiah 29:11 *I know the plans I have for your, declares the Lord. Thoughts of peace, and not of evil, to give you an expected end.*

Jeremia 29:11:

Ek beplan voorspoed vir julle, nie teënspoed nie. Ek wil hê dat julle hoop vir die toekoms moet hê. Ek het ʻn toekomsverwagting vir jou.

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CHAPTER ONE

INTRODUCTION AND OVERVIEW

1. INTRODUCTION

While physics education researchers have compiled substantial evidence that student learning can be improved by using research-based instructional strategies in lieu of traditional instruction (Henderson, 2003), and that the traditional ‘plug and chug’ presentation in physics classes (emphasising solution execution) does not assist students to effectively learn how to solve problems or understand the physics concepts being taught (Van Heuvelen, 1991), adoption of research-based instructional strategies remains low (Fraser et al., 2014). A research-based instructional strategy is defined as “a specific pedagogical approach that has shown effectiveness through empirical measurement (quantitative and/or qualitative)” (Fraser et al., 2014, p. 1).

Dominicus and Linder (2005) commented that the university physics teaching environment is underexplored. Similar arguments came from Ramsden and Martin (1996) and (Healey, 2000) asking for a more thorough investigation of the nature of higher education teaching. These arguments above suggest lecturers “need to adopt a scholarly approach to teaching” that “involves reflection; inquiry, evaluating, documenting and communicating about [their] teaching”; and collecting and presenting “rigorous evidence of their effectiveness as teachers” (Healey, 2000, p. 170). Recently the South African

Institute of Physics undertook a review of undergraduate physics education in public higher education institution, recommending “the utilization and production of research into more effective ways of teaching under-prepared students” and the employment of more “appropriate and rigorous techniques of monitoring and evaluating Physics teaching” (CHE-SAIP, 2013, pp. 34-35).

However, despite the benefits and importance of applying research-based pedagogy in physics classrooms, Fraser et al. (2014) report that many lecturers have not made use of physics education resources available to them, find it difficult to make sense of the classroom situation, and they seem to underestimate their role in the development of representational competence and fluency in physics students.

2. REPRESENTATIONS

One of the scientific abilities needed when engaging in the construction of knowledge or solving of problems is “the ability to represent physical processes in [multiple] ways” (Etkina et al., 2006, p. 1). Representations and representation-based activities are central practices of science and are regarded as “the entities with which all thinking is considered to take place” (Gilbert, 2010, p. 1). The use of representations are consequently considered as central to both the conduct and learning (and concomitantly, teaching) of science (Gilbert, 2010, p. 1; Wu & Puntambekar, 2012) and is considered a necessary condition for expertise in physics (Kohl, 2007). Students use representations as tools to interpret and reason about representations and to support their emergent understandings, teachers use models, pictures and symbols to present scientific ideas, and instructional materials include various representations to illustrate scientific content (Wu & Puntambekar, 2012).

The concept representation in educational research "has been defined loosely and referred to a range of transformations that conceptualize, visualize, or materialize an entity into another format or mode" (Wu & Puntambekar, 2012, p. 4). In the context of this study it is necessary to distinguish between external representations and internal or mental representations. External representations span the whole range from concrete to abstract forms e.g. physical objects, pictures, diagrams, spoken language or written symbols (Gilbert, 2010) and are regarded by Lesh, Post, and Behr (1987a) as the way by which ideas are meaningfully communicated. Internal representations on the other hand are considered to be mental images that correspond to internal formulation of the reality that we see around us (Lesh et al., 1987a). Such representations, for example "cognitive or mental models, schemas, concepts, conceptions, and mental objects" (Janvier, Girardon, & Morand, 1993, p. 81), are held individually and are as such illusive and not directly observed (Dixon & Johnson, 2011). Any discussion on representations from this point onwards will refer to the concept external representations.

The benefits associated with the use of representations in the learning, and consequently teaching, of physics is well documented (Airey & Linder, 2009a; Kohl & Finkelstein, 2006a, 2006b; Kohl, Rosengrant, & Finkelstein, 2007a, 2007b). As such, the important role of representations in the learning of physics has attracted the attention of researchers (Airey & Linder, 2009b; Kohl & Finkelstein, 2006a; Kohl et al., 2007b). Unfortunately the use of representations has been identified as one of the aspects of physics students experience difficulty with (Ornek, Robinson, & Haugan, 2008). "Novice physicists (generally introductory physics students) often struggle both with using the canonical representations of physics and with the coordination of multiple representations" (Kohl, 2007, p. 3).

Ainsworth (1999) identifies the relative strengths and weaknesses of representations, misinterpretations that occur, difficulties in terms of translation and transfer between the representational formats, and the most appropriate methods of engaging different representations into physics education as issues for consideration. Studies done in undergraduate physics contexts, identified student difficulties stem from the nature of physics concepts, the way in which a physics course is taught, and physics problems which are sometimes very vague (Ornek et al., 2008; Redish, 1994, 1999). In the words of Ornek et al. (2008, p. 35) “It seems students and [lecturers] live in different worlds”.

3. STATEMENT OF THE PROBLEM

The implementation of scholarly contributions focusing on physics education research by discipline lecturers is contested territory. There are mixed results in literature on the actual and potential impact research on teaching and learning physics have on lecturers’ teaching (Henderson & Dancy, 2008; Leach, 2007). Some studies (c.f. the study done by Henderson & Dancy, 2009 in the US) report widespread ‘awareness’ of research-based instructional strategies for introductory physics, but the strategies may be implemented inappropriately or discontinued. Reflection is also not an easy and straightforward process since much of what contributes to the success of e.g. lesson or project “is the coming together of, and interactions amongst many variables, some of which are in themselves unstable” (Hennessy, 2006, p. 184).

The need to engage physics lecturers with the body of physics education research available to them, and to get them to reflect on their own teaching practice, influenced the design of this study. While a number of researchers have researched physics education from a student learning perspective (De Cock, 2012; Hegde & Meera, 2012; Kohl & Finkelstein, 2005; Redish & Steinberg, 1999) there are (i) fewer studies focusing on the observation and analysis of lecturer practice, (ii) a paucity of research into the instructional use of representations by physics lecturers in general, and by introductory physics lectures in particular, and (iii) there is no specific tool that can be described as objective, valid, reliable and practically applicable, that is available to assist physics lecturers' to meaningfully reflect on their practice.

Using a definition of the scholarship of teaching based on "engagement with research into teaching and learning, critical reflection of practice, and communication and dissemination about the practice of one's subject" (Healey, 2000, p. 169), Martin and his colleagues (Martin, Benjamin, Prosser, & Trigwell, 1999) identified three essential and integrated elements in a scholarship of teaching, namely:

- "engagement with the scholarly contributions of others on teaching and learning [which will be represented by the physics education research body of research knowledge];
- reflection on one's own teaching practice and the learning of students within the context of a discipline; and
- communication and dissemination of aspects of practice"

(reported by Healey, 2000, p. 171).

A further aspect of importance when focusing on the scholarship of teaching in higher education is that the scholarship should not be separated from the content of the discipline being taught (Healey, 2000). As Rice (1995, p. vi) notes: "improvement in teaching needs to be rooted in the intellectual substance of the field". As such, this study set out at designing and developing an objective, valid, reliable and practically applicable artefact to measure the instructional use of representations by lecturers in introductory physics classes and to trigger and enable reflection on their instructional affordances, which situates the study within the emerging paradigm of design-based educational research.

4. UNDERLYING ASSUMPTIONS AND PURPOSE OF THE STUDY

In defining the purpose of the study, which is to develop a reflective tool (an artefact) for introductory physics lecturers to assist them to:

(i) identify the areas of their own use of representations where they do not implement research based knowledge around teaching (and learning) with and from representations

(ii) reflect on the instructional affordances offered by their current instructional use of representations,

certain assumptions were made. These assumptions can be categorised as theoretical assumptions and methodological assumptions.

Theoretically, the research is based on the assumption that teachers value information that they can use to improve their instruction. Linked to this assumption is another theoretical assumption that lecturers will reflect if provided with an appropriate trigger for their reflection. Given the reluctance of subject lecturers to implement research oriented strategies or interventions as part of their teaching practice (Dancy & Henderson, 2010), combined with complaints of not having the time to engage with the scholarly contributions available in literature (Dancy & Henderson, 2010), the assumption is that, if lecturers are provided with an easily accessible and subject-pertinent reflective tool or artefact, they will be more amenable and better able to meaningfully reflect on their teaching practice.

Another assumption that guided the design of the study is that lecturers would likely differ in the extent to which they engage in reflection on their teaching (Kreber, 2005). One consideration guiding this assumption is that these differences might possibly be linked to lecturers' conceptions of teaching and learning (Prosser & Trigwell, 1999). The particular beliefs lecturers hold about teaching, could also play an important role in the extent to which they feel motivated to engage in certain kinds of reflection but not in others (Kreber, 2005). The overarching assumption of this study is that existing physics instructional "practices are inadequate or can, at least, be improved upon, so that new practices are necessary" (Herrington, McKenney, Reeves, & Oliver, 2007, p. 6). All of the assumptions noted above pointed the direction of the study towards a design-based research approach (Edelson, 2006; Herrington et al., 2007).

Methodologically, the first assumption made that influenced the choice of data collection method and instrument is that it is possible to capture a detailed & rigorous account of instruction (Hora & Ferrare, 2014) and that instruction need not only be measured and described with self-reported accounts of teaching methods (Hora & Ferrare, 2014). A further assumption made was that the instructional use of representations can be observed and categorised from a video-clip data of classroom teaching via an observation protocol, where after further artefacts can be designed to enable participants to reflect meaningfully on their practice (Rosaen, Lundeberg, Cooper, Fritzen, & Terpstra, 2008).

In essence, therefore, the purpose of this study was to develop an encompassing artefact that would accurately and reliably describe the instructional practices of physics lecturers in the context of their undergraduate physics classes and, in the process, enable them to reflect on their practice in a way that surpasses self-reported reflection methods that have been used in the past (Franklin, 2012).

5. AIM AND OBJECTIVES

The aim of the research is therefore twofold. The practical aim is to design and develop an artefact (or set of artefacts) in the context of introductory physics that would accurately and reliably describe lecturers' instructional use of representations and enable them to reflect meaningfully on these descriptions in order to reduce the gap between their current instructional practice and the expected research-based instructional practices as described by contemporary research. The theoretical aim is to understand and describe the characteristics of artefacts that promote reflection in general.

It was assumed that this aim could be accomplished through the realisation of the following research objectives, namely to:

1. Identify a suitable strategy to engage physics lecturers in reflection on their instructional use of representations.
2. Create a systematically and rigorously designed product intended to meet the research design goals.
3. Produce data that indicates the validity and effectiveness of the product.
4. Establish whether the strategy designed to trigger physics lecturers' reflection on their instructional use of representations can be successfully implemented.

5. Determine whether the intervention as conceived is able to achieve its goal of engaging lecturers in reflection on their instructional practice.

6. RESEARCH QUESTIONS

In order to achieve the dual goal of the research the following main research question was formulated:

> *In what ways can reflection on instructional practices by introductory physics lectures be influenced using a design-based research approach?*

The following sub-questions were formulated to assist in answering the main research question:

- How might lecturers be engaged in reflection on their instructional use of representations?
- How was the intervention strategy received by the participating lecturers?
- Did the intervention as conceived trigger physics lecturers' reflection, using a design-based research approach?

7. CONTEXT OF THE STUDY

The study was undertaken at the Nelson Mandela Metropolitan University (NMMU). This university serves a diverse student population where more than half of the students speak a language other than English at home. First-year students arrive with varied background knowledge in physics as a result of both individual differences and differences that exists in the quality of education in the South African schooling system (Taylor, Fleisch, & Shindler, 2008). Introductory physics is offered in a variety of qualifications in the faculties of Science, Health Sciences, Education and the School for Engineering, spanning from diploma qualifications to degrees which either focus on majoring in physics or having physics as an auxiliary subject in the first year curriculum. Two academic departments, namely the Physics and Engineering departments are involved in the offering of introductory physics content to these students. Each of these qualifications has a different set of selection criteria and requirements.

The transition from school level to university level physics appears to be a major obstacle in student progression (Buffler & Leigh, 2005; Scott, Yeld, & Hendry, 2007). As the use of representations has been identified as an obstacle to engaging with physics successfully (Fraser et al., 2014) a decision was made to focus on the instructional use of representations by introductory level physics lecturers. While all students registered for the subject have some experience of physics representations based on their schooling experience (diSessa & Sherin, 2000), when they enter the lecture hall there are numerous confounding variables (for example their background knowledge, their attitude towards learning physics, etc.) including their reception of the representations used by the lecturers. As such, introductory physics lecturers provide an important bridge for students in transition from school to higher education physics. It is assumed therefore that it is important that lecturers be able to reflect on the description and characterisation of their use of representations, and that such reflection should help them improve their practice and consequently improve their students' representational fluency. While important, the aspect of learning of physics by the students and their representational fluency is not the focus of the study. The focus is on this aspect's precursor, namely the nature of representational use by lecturers during physics instruction across the range of introductory physics programmes offered at the NMMU and their ability to reflect on their practice.

8. RESEARCH DESIGN AND METHDOLOGY

The study aims at, on the one hand, exploring and describing the instructional practices of lecturers in terms of the representations they use and, on the other hand, investigating the influence of resultant design-based artefacts on the type and level of lecturer reflection. This study can be classified as an exploratory design study Van den Akker, Branch, Gustafson, Nieveen, and Plomp (1999). Its emphasis is on a preliminary investigation of the feasibility of an artefact to promote physics lecturers' reflection on their instructional use of representations. This type of design is underpinned by a pragmatic set of question-driven philosophical assumptions that are discussed in detail in chapter three. The pragmatic paradigm allows one to produce multi-faceted answers to the research question formulated, i.e. to bring questions that have been asked in another field (in this case academic staff development) to the attention of physics education researchers, and to pursue these questions with methods that are appropriate to the field of physics education research. This approach required a three-phase design for the study.

The first phase focused on grounding the design in the context of the study, the research problem identified and the knowledge-base for the two domains in which the problem is situated, namely reflection and professional development of physics lecturers and a semiotic affordance perspective on using representations during physics instruction (Chapter two). The second phase of the research design involve the conceptualisation of the design by developing a construct, model, method to solve the research problem identified, followed by the instantiation of the designed artefact. These processes are described in Chapter three and the results of the instantiations of the designed artefact are provided in Chapter four. The final phase of this design-based research project entails the assessment and evaluation of the designed artefact for its feasibility to address the research problem and the practical resonance it has with the intended users of the artefact (the introductory physics lecturers).

9. SIGNIFICANCE OF THE STUDY

It appears that, after extensive literature searches, no suitable observation protocol for producing lecturer profiles of their instructional use of representations instrument currently exists. As such, the initial problem that was identified for this study was whether a valid, reliable and usable (practically applicable) observation protocol for producing lecturer profiles could be developed. The benefits of developing such a valid and reliable observational instrument would be twofold. Firstly the availability of the instrument would contribute to the methods available to the physics education research community to determine the use and understanding of the affordances offered by representations by lecturers. Secondly, the instrument could provide the basis for developing an artefact for the analysis of personal instructional use of representations in a physics context. Furthermore, studying how lecturers use, for example, representations as part of their instructional practice should contribute to the physics education research community's understanding of enactment of the disciplinary discourse (Speer, Smith, & Horvath, 2010).

As noted earlier, most research in the area of representations focuses on learning with representations (see e.g. Ainsworth, 2008; Waldrip, Prain, & Carolan, 2010). There are fewer empirical studies that focus on the pedagogical aspects of representations and there are none which use a design-based approach for promoting reflection on the use of representations by physics lecturers. This study, which investigates the influence of a design-based artefact to enable reflection by physics lecturers' on their teaching practice, has the potential to contribute to understandings in higher education. The findings of the study have the potential to help lectures gain insight into their own teaching practice, enact sharing between education researchers and physics lecturers, and provide an analytical framework for the physics education research community (Airey, 2011). In this way the research should make a contribution to the debate around the pedagogical use of representations in physics settings.

Finally, it was believed from the outset that the processes experienced while developing the artefacts, as much as the final product, would contribute to the body of research on the use of representation in physics teaching and would help fill a void in the literature in terms developing ways of influencing lecturers' instructional use of representations in introductory physics classrooms.

10. DELINEATION AND LIMITATIONS

As noted earlier, the focus of the study is not on what is going on in the minds of students, but on lecturers' use of representations as part of their instruction. Similarly, the literature review is limited to the process of reflection and research on instructional use of representations, not on learning via representations. The profiles developed and presentations of findings via use of the artefacts are intended only to show that heuristic tools can be developed to possibly influence lecturers to reflect on their own instructional use of representations. They are not to be considered as exemplars of practice. In turn, the methodology focuses on aspects that relate to design-based research. The study is limited in scope to include only five lecturers' instructional practice at the NMMU. As such caution needs to be exercised when considering the generalizability of the findings to other higher education institutions and contexts. Nevertheless, the process decried and used are applicable to design-based activities in a wide range of settings.

11. THE STRUCTURE OF THE THESIS

This manuscript, which subscribes to most of the requirements of the American Psychological Association (APA) 6th Edition referencing style, is divided into the following chapters. This initial chapter described relevant concepts related to the study, presented the research problem, formulated research question and sub-questions, provided a rationale for the study and its context, illuminated its significance and limitations, and outlined the structure of the thesis.

Chapter two discusses issues relating to relevant theories on reflection and reflective practice with the purpose of professional development as it relates to lecturers in a higher education context. The issues relating to relevant theories on representations include the following: semiotic views of representation theory; affordance view on representations; disciplinary discourse view of representations; learning and constructing knowledge with representations in a physics context; and research studies focusing on teaching with representations in a physics context. As such, the chapter provides the theoretical framework for the study. The review of the literature further served the purpose of facilitating the design of the preliminary artefacts that will seek to address the identified problem.

Chapter three describes the research design of the study. It contains, amongst other things, a discussion on the paradigmatic stance taken in the research, and how the study adheres to the principles of design-based research. An overview of the three phases of the study is given. The chapter also discusses the development of the various artefacts designed and developed, followed by a discussion of the instantiation of the artefacts. The chapter is concluded by discussion the process followed in the evaluation of the artefacts.

Chapter four reports on the results generated during the three phases of the research project, namely the grounding phase; the conceptualisation phase which includes the results from the development of construct and the observation protocol; as well as the instantiation of the designed artefacts which serves as proof-of-concept; followed by the validation and evaluation phase.

In Chapter five the main findings of the study are synthesised in a preliminary attempt to theory building around stimulating and promotion of reflection by lecturers on their instructional use of representations. The discussion takes place within the framework of the design methodology, the design framework, and the design principles. The theory building phase is followed by an evaluation of the design process using the seven criteria proposed by Hevner, March, Park, and Ram (2004).

Chapter six conclude the study with a reflection on the alignment between the research questions, the design process and the main findings of the study. Suggestions for future research and caveats in terms of the limitations of the research findings are also provided in this chapter.

CHAPTER TWO

THEORETICAL FRAMEWORK AND LITERATURE REVIEW

1. INTRODUCTION

The aim of this chapter is to articulate the theoretical framework for this study, or in the words of Franklin (2012, p. 44) to present “a set of interrelated constructs (concepts), definitions, and propositions that present a systematic view of [the] phenomena”. Redish (2004, p. 2) proposes that the purpose of providing a theoretical framework is to establish “a shared language and shared assumptions that can both guide and allow us to compare different approaches and ways of thinking”. The framework of this study is rooted in notions of the instructional use of representations in introductory physics classrooms and lectures’ ability to reflect on their own competencies using reflection based on a purposively developed classroom observation protocol.

The chapter is divided into three sections. I begin with a focus on the theoretical perspectives that are used as tools to understand reflective practice in higher education when using a semiotic affordance lens. In the next section I discuss previous research in the teaching and learning via representations in science in general and physics in particular. Since the focus of my dissertation is on instructional representations that are used by lecturers to impart the knowledge to students, the bulk of this section focuses on representations teachers construct during their classroom practice. The body of representations-related research is vast, so this chapter only considers select subcategories that are most relevant to the study with emphasis on work with university-aged student and aims at providing a coherent summary of studies around the use of multiple external representations (MERs) in the teaching and learning of science in general and physics in particular. The review provides the basis and argument for the development of an instrument for the promotion of reflection on the instructional use of representations and their associated affordances and constraints. I conclude by discussing the factors that drove the development and use of the observational protocol designed for this study.

2. OVERVIEW OF THEORETICAL FRAMEWORK

It is well documented that teachers, or in the context of higher education, lecturers, are considered to be the most powerful, durable and effective agents of educational change (Mälkki & Lindblom-Ylänne, 2012; Moon, 2013; Sellars, 2012). Sellars (2012) argues that higher education teachers should take effective, positive action in the classroom context to improve the educational outcome of their students. Henderson, Beach, and Finkelstein (2011, p. 952) identified four strategies to support change in the instructional practices used in undergraduate science, technology, engineering, and mathematics (STEM) courses, namely “disseminating curriculum and pedagogy; enacting policy; and developing shared vision; and developing reflective teachers”. Reflection is seen as a catalyst for change in professional practice (Ghaye, 2005). Sellars (2012, p. 461), in agreement with this view, argues that the quality of educational change will “only be as reliable and proficient as the teachers’ individual capabilities for reflective practice and the development of self-knowledge”.

One way of implementing Sellars' directive is to improve physics lecturers' knowledge about their own instructional use of representations in their classrooms, as well as the instructional affordances offered by these representations in order to improve the educational outcome of their students. External representations are key components of the physics curriculum and play an important role in cognitive function, particularly in so far as individuals interpreting the meanings of, and applying meanings to, these representations (Podolefsky & Finkelstein, 2008). In other words, physics lecturers need to engage in authentic reflection around their instructional use of representations in their introductory physics classes if they want improvement in the learning of physics.

3. REFLECTION AND PROFESSIONAL PRACTICE

Numerous articles have been published over the past two decades around reflection in professional practice and education (Finlay, 2008; Hatton & Smith, 1995; Mälkki & Lindblom-Ylänne, 2012). Reflection in higher education institutions is increasingly being seen as a process of professional development (Ryan & Ryan, 2013), pedagogical growth (Ramsden, 1992; Trigwell, Martin, Benjamin, & Prosser, 2000) and a prerequisite to quality teaching (Mälkki & Lindblom-Ylänne, 2012); something which is appealing as it raises the likelihood of learning being relevant and meaningful to those who engage in it (Higgins, 2011).

On the face of it the concept 'reflection' appears not to be contentious. However, this may not be the case judged on some of the comments made by researchers. For example (Moon, 2001, p. 2) commented that "Reflection is theorised in so many different ways that it might seem that we are looking at a range of human capacities rather than apparently one". To complicate matters even more, what is understood as 'reflective practice' varies considerably within various intellectual traditions and disciplines (Fook, White, & Gardner, 2006), and even within the same discipline (Finlay, 2008). Thompson and Pascal (2012) argue that the nature of reflective practice theory is relatively underdeveloped, while Akbari (2007) adds to the debate by pointing to the various historic and theoretical trend and philosophies that influenced the term reflection, resulting in leaving it open to different interpretations.

The question then arises: What is regarded as reflection and reflective practice in the context of higher education teaching by theoreticians? Attempting to answer this question warrants a closer look at the various conceptualisations around reflection and reflective practice, specifically in the context of higher education teaching.

3.1 Conceptualising reflection

The classical or traditional approach to conceptualising reflection includes authors such as Dewey, Habermas, and Kolb (as reported by Leijen, Valtna, Leijen, & Pedaste, 2012). These writers distinguish between routine action and reflective action. In their view reflection serves the purpose of becoming conscious and thoughtful about one's action, opposed to acting according to a trial and error scheme while dealing with problematic situations. Reflection is taken as thinking about our actions (Leijen et al., 2012), contrasting it with impulsive and routine actions frequently undertaken in a passive, largely unthinking way (Akbari, 2007). Although many teachers reflect on their teaching practice, (Moon, 1999) suggests that these reflections are not always in the deliberate manner which would enable them to progress in their thinking or action.

Habermas (1972), as reported by Moon (2001), focused on the way in which humans process ideas (involving reflection) and construct them into knowledge –

technical, practical and emancipatory knowledge interests (Leijen et al., 2012). Each way of knowing is constructed, guided, and shaped differently. Kolb (1984) considered reflection as a mental activity that has a role in learning from experience, Many researchers who have written about reflection developed their ideas from these classical theorists (see e.g. Boud, Keogh, & Walker, 1985; Moon, 1999) or offered critique on the classical approach to reflection (see e.g. Eraut, 1995).

One such theorist is Schön whose influential work moved away from the above mentioned traditional approaches with their emphasis on technical rationality that claims a knowledge base that is specialised, clearly bounded, scientific and standardised, to seeing reflection as a form of art by which practitioners deal with uncertainty, uniqueness and instability on a daily basis (reported in Thompson & Pascal, 2012). As real life problems experienced by professionals are commonly complex, mostly ill-defined and often involve contradictory or no theories (Thompson & Pascal, 2012), a reflection approach where the problem is identified; an adequate theory is available; and this theory is applied to solve the problem was conceptualised by Schön (1983). His ideas about improving practice through reflectivity and theory-in-use have stimulated much deliberations around the role of espoused theory (research theory) and theory-in-use (Ryan, 2013). Schön argued that the espoused theory learnt in formal professional training is not the theory that proficient professionals eventually use to guide practice. Their expertise is rather built from their practice (theory-in-use) by being reflective. Schön further noted that professionals are not necessarily able to describe the basis on which they act making their theory-in-use most likely tacit. A particular role of professional development is to make this 'knowing-in-action' explicit so that it can be the subject of further reflection and conscious development, namely reflection-on-action (Moon, 2001).

Reflective practice consequently proposes an approach where greater emphasis is placed on integrating theory and practice (Thompson, 2000). Thompson and Pascal promote the notion of 'theorising practice'– that is, the process of beginning with practice and drawing on a professional knowledge (and value) base to make sense of it in order to be able to engage with the practice challenges involved (Thompson & Pascal, 2012). This perspective is summed up by Thompson and Pascal's (2012) quote:

> *"Professional practice is not seen as a technical process of applying (scientifically derived) solutions to practice problems. More realistically, it is a matter of wresting with the complexities of both theory and practice, using professional artistry to move forward as effectively as possible. ... This involves tailoring theoretical and research-based knowledge to fit the circumstances encountered in specific practice situations"*
>
> (Thompson & Pascal, 2012, p. 314).

Building on the argument to provide an alternative to technical rationality with its technical approach to fixing problems, Thompson and Pascal (2012) argue that professional practice is more a matter of art or craft than science – drawing on formal theory as and when appropriate while wrestling with the complexities of both practice and theory, while using professional artistry to move forward as effectively as possible (Thompson & Pascal, 2012). Schön sees the artistry of masterful teaching as the capacity to make sense of the unknown and uncertain situations by testing one's knowledge to generate new learning outcomes (as reported by Brown, 2014). Professional artistry is consequently a combination of high levels of technical competency and the ability to adjust in the moment to sudden or rapidly changing situations – reflection-in-action (Schön, 1983, 1987).

Other scholars have sought to add to Schon's definitions of reflection-on-action and reflection-in-action. Killion and Todnem (1991) conceptualized reflection-for-action as a further goal of reflection.

They argue

> *"[w]e undertake reflection, not so much to revisit the past or to become aware of the metacognitive process one is experiencing (both noble reasons in themselves), but to guide future action (the more practical purpose)"*
>
> (Killion & Todnem, 1991, p. 15).

In this way reflective practice is proposed as an alternative to the process of beginning with theory and trying to 'apply' it to real life practice. Muir and Beswick (2007, p. 77) proposes the use of the term reflective practice as "a more accurate term describing reflection that is deliberate and can be focused on events or incidents, and personal experiences": – thus involving noticing aspects of your own practice that may be triggered by a question from an outside observer, and then recognising and working on issues of concern (Moon, 1999).

3.2 Conceptualising reflective practice in the context of higher education teaching

As is the case with the concept reflection, understanding of the concept reflective practice also varies within disciplines and intellectual traditions (Finlay, 2008; Fook et al., 2006). What is clear from literature is that "reflective practice is distinct from everyday thinking because it is deliberate and a purposeful activity interested in turning experience into knowledge" (Rolfe, 1996, p. 28). Kerschner's (2006) characterisation of a reflective practitioner reflects this sentiment.

> *"Being a reflective practitioner involves the acts of thinking and teaching, knowing and doing. To be a reflective practitioner who reflects-for-action, one must engage in reflective thinking and teaching. The end product is not reflective thinking itself, but rather the teaching and learning that occurs"*

(Kerchner, 2006, p. 124).

Reflective practitioners in the context of higher education teaching are consequently lecturers who move beyond asking utilitarian questions about their daily and typical teaching routine to seek to discover perspectives on who is learning, why they are/are not learning, and how best to present the disciplinary material so that it is accessible for all students (Kerchner, 2006).

Drawing on the various definitions in literature, Fook et al. (2006) identify the following elements of reflective practice:

- "a process (cognitive, emotional, experiential) of examining assumptions (of many different types and levels) embedded in actions or experience;
- a linking of these assumptions with many different origins (personal, emotional, social, cultural, historical, political);
- a review and re-evaluation of these according to relevant (depending on context, purpose etc.) criteria;
- a reworking of concepts and practice based on this re-evaluation"

(Fook et al., 2006, p. 12).

The contexts for the use of reflection may serve many different interests, for example it may include learning about and improving practice, as a way to increase accountability to existing norms (Fook et al., 2006), or as is the case in this research, to learn to connect theory and practice related to the instructional use of representations in physics and improving and changing the practice of introductory physics lecturers. But, "[p]rofessional or academic reflection is not intuitive, and requires specific … intervention to do well" (Ryan & Ryan, 2013, p. 244). Daloz (2000) advocates the engagement in both reflection and reflective discourse for learning to be transformational (create change). He identifies four conditions that are particularly salient in facilitating development, namely "the presence of the other, reflective discourse in a climate that is both supportive and challenging, a mentoring community, and opportunities for committed action" (Daloz, 2000, p. 112).

The notion of a collaborative aspect of reflection and reflective practice is emphasised by many researchers and practitioners (Moon, 1999). For example Simon, Campbell, Johnson, and Stylianidou (2011) confirm the importance of discussion with trusted colleagues to help with reflection. "Another person can provide the free attention that facilitates reflection, ask challenging questions, notice and challenge blocks and emotional barriers in reflection" (Moon, 1999, p. 172). In contemporary professional practice reflection occurs in contexts that involve social and collective actions (Boud, 2010). Husu, Toom, and Patrikainen (2006) refer to this reflection with others as guided reflection.

For effective reflection to take place, a reflective discourse climate is needed which includes access to accurate information, freedom from coercion, openness to other perspectives and new ideas, an ability to weight evidence and assesses arguments objectively (Mezirow, 2000). Such a climate emphasises participatory processes of dialogue and communication, rather than closed judgement of practices (Fook et al., 2006). Ghaye (2005) refers to this process as a reflective conversation. The reflective dialogue can be an internal dialogue or conversation within oneself (what Hatton & Smith, 1995 describe as dialogical reflection) – or it could be a reflective conversation with colleagues with the focus on solving problems collaboratively. Conversations carefully framed as reflective conversations have the power to not only generate deep understanding, but to also create change (Brown, 2014).

Different uses of reflection in reflective practice will, according to Fook and colleagues (2006, p. 12), "vary in the number and type of assumptions focused on, the types of processes involved, the criteria for review of assumptions, and of course the purposes for which the process is used". They advocate the use of a framework involving different levels and stages (with one stage at least focusing on the application of reflective learning to practice itself) for the reflective process. They further argue that it "may be counterproductive to undertake any reflective process in organised learning settings without being clear about the specific purpose and process of reflection in relation to the particular context" (Fook et al., 2006, p. 12). It can be concluded that reflective practice is both contextual and particular in nature.

3.3 Conceptual concerns around reflection and reflective practice theory

The traditional form of reflective practice played an important role in establishing reflective practice theory and the benefits of reflective practice is widely acknowledged (Higgins, 2011). However, current theories around reflection are not without its problematic issues. Reflective practice has unfortunately acquired 'buzzword' status, frequently resulting in oversimplified practice that bears little relation to the thinking they claim to be based on (Finlay, 2008; Thompson & Pascal, 2012). The terminology around reflective practice and reflection is contested with the undiscerning and sometimes uninformed use of terminology and their conflation (Fook et al., 2006) as seen in the discussion on the difference between reflection, critical reflection and reflexive practice to follow. Given the concerns, Finlay (2008) argues for the cautionary and flexible use of the contested terminology and accompanying reflective practice theory. In addition, Finlay (2008) has highlighted some concerns related to the views originally put forward by Schön, namely the oversimplification of Schön's original ideas when translated into practice (Thompson & Pascal, 2012), the dilution of the original intentions (Lyons, 2010), and an acknowledgement of the difficulty to operationalize reflection in studies (Lyons, 2010).

Another concern relates to the neglect of the significance of meaning making (seen as the process at the heart of the reflective conversation with the situation) in the traditional form of reflective practice (Thompson & Pascal, 2012). The emphasis placed on the individual's practice and a comparative neglect of the social and situated dimensions of professional practice is problematic in the complex context of higher education teaching and learning. Fook (2010, p. 38) warns that only a reflective practice that attempts to understand "the individual in social context" can be truly critical. Reflective practice as social critique focuses attention on the wider discursive, social and political context (Thompson & Pascal, 2012). Schön's work can therefore be seen as an oversimplification of the complex hermeneutical processes involved in reflective practice (Thompson & Pascal, 2012). In the light of literature pointing to both the relatively underdeveloped nature of reflective practice theory and a common tendency to misread that theory, Thompson and Pascal (2012) argue for developing the theory base of reflective practice and improving its implementation in practice.

Reflection, critical reflection and reflexivity

The terms "reflection, critical reflection and reflexivity are often wrongly assumed to be interchangeable" (Finlay, 2008, p. 6). Each of these concepts has its own epistemology and need to be distinguished and used carefully in order to avoid confusion (Leijen et al., 2012). The followers of the pragmatic and the social critical theory traditions interpret reflection differently. The classical or traditional perspective on reflection, subscribing to a pragmatic tradition, refers to reflection as the process of thinking about the work we undertake either at the time (reflection-in-action) or at a suitable opportunity thereafter (reflection on action) in a mostly cyclic process with a practical focus. The hallmark of reflection is subsequently informed practice that surpasses habitual or route practice (Thompson & Pascal, 2012).

Critical reflection on the other hand is interpreted differently by the followers of the social critical theory traditions (Leijen et al., 2012). For these theorists the use of critical theory as ideology is considered one of the defining features of critical reflection (Fook et al., 2006). They argue that "reflection is … a value-laden enterprise" (Hennessy, 2006, p. 184) in which reflective teachers, based on Zeichner and Liston's (1996) argument, move beyond asking technical questions about the effectiveness of their practice, to a critical examination of their educational values and whether their practice lead to change. Critical reflection resultantly seeks to enable transformative social action and change through the use of critical theory as ideology (Finlay, 2008) or in the words of Kember, McKay, Sinclair, and Wong (2008):

> *"… critical reflection implies undergoing a transformation of perspective. Many of our actions are governed by a set of beliefs and values that have been almost unconsciously assimilated from our experiences and environment. To undergo a change in perspective requires us to recognize and change these presumptions. To undergo critical reflection it is necessary to conduct a critical review of presuppositions from conscious and unconscious prior learning and their consequences"*

(Kember et al., 2008, p. 374).

The concept reflexivity on the other hand, is viewed as a turning "back on oneself" (Lawson, 1995, cited by Cunliffe, 2002, p. 17) in which we show a willingness to challenge personally held values, beliefs and assumptions (Phelps, 2005). For Cunliffe (2002, p. 38) it means "complexifying thinking or experiences by exploring contradictions, doubts, dilemmas and possibilities". It embraces subjective understanding in order to think more critically about one's values and the effect of one's actions values and the effect of one's actions on others (Cunliffe, 2004).

> *"Reflexive practitioners engage in critical self-reflection: reflecting critically on the impact of their own background, assumptions, positioning, feelings, behaviour while also attending to the impact of the wider organisational, discursive, ideological and political context"*

(Finlay, 2008, p. 6).

Thompson and Pascal (2012) argue that a well-developed approach to reflective practice would incorporate both the traditional notion of reflection as an analytical process and reflexive approaches with their emphasis on undertaking a self-analysis to acknowledge the influence of ourselves and that of our social and political context on the type of knowledge we generate and the way we generate it.

Finlay and Gough (2003) places these three concepts on a continuum with reflection at one end taken as being thoughtful about something during or after the event, reflexivity on the other extreme (a dynamic process involving continuous self-awareness) and critical reflection taken as to be somewhere in-between these two ends.

3.4 The process of reflective practice

Based on research literature, it can be concluded that the process of reflective practice can take place in different ways and at different places in the teaching practice of lecturers. Reflection can occur prior to instruction, concurrent with instruction, in retrospect to instruction or at such a point after the class that it may be disconnected from teaching actions (McAlpine & Weston, 2002). Reflection may also occur when considering future actions (Killion & Todnem, 1991). The value of reflection can resultantly be seen as helping professionals learn about and improve their practice (Rolfe, 2014; Schön, 1983). This stance taken towards reflection is a more generic orientation as explained by (McAlpine & Weston, 2002, p. 59), stating that "any reflection is good because [lecturers] can then be more intentional and deliberate in their thinking about teaching". Another aspect of reflection is its ability to serve as catalyst for turning experience into knowledge about teaching (McAlpine & Weston, 2002). As argued by McAlpine and Weston (2002):

> *"Ongoing use of the process of reflection is essential for building knowledge, and increasing knowledge increases one's ability to use reflection effectively and to develop as a teacher"*
>
> (McAlpine & Weston, 2002, p. 60).

The value of reflection in the context of higher education pedagogy is reported to be in “enabling the [lecturer] to build more sophisticated understandings of teaching and learning” (Mälkki & Lindblom-Ylänne, 2012, p. 35). Reflection in this context is therefore anchored in teaching action and, at this point, it may be more accurate to refer to reflective practice rather than reflection. From the discussion above it may seem that reflection leads to reflective practice and consequently an enhancement of the practice. Several scholars have warned that setting off reflection or incorporating its benefits to action is not self-evident (Kreber, 2004; Mälkki & Lindblom-Ylänne, 2012). This link between reflection and action in relation to higher education teachers’ pedagogical growth has been identified as one of the aspects of reflective thinking that is poorly understood (Mälkki & Lindblom-Ylänne, 2012, p. 33). A crucial issue for professional development of lecturers would therefore be to pay attention to factors that intervene between reflection and action; either enabling a bridge or preventing a link from forming.

Both Dewey (1989/1933) and (Mezirow, 1994) argued that reflection is launched as a response to an event that would trigger a need to re-consider one’s habitual ways of doing and being. Reflection is however not an automatic response to such a problematic situation, but only starts if the situation is faced and examined (Mälkki & Lindblom-Ylänne, 2012). Dewey furthermore argue that in order to face the situation and examine it, the problematic situation should be directly felt and experienced, in contrast with artificial, ready-made problems or assigned tasks (as reported by Mälkki & Lindblom-Ylänne, 2012). It is clear that having actual experiences upon which to reflect is of critical importance in reflective practice (Boud et al., 1985). “It is the analysis of these multiple experiences through reflection which enables [a lecturer] to detect patterns that then lead to knowledge” (McAlpine & Weston, 2002, p. 63). The process of reflection, representing the "external actions" of the lecturer and the "arena in which teaching is enacted", is therefore grounded in experience (McAlpine & Weston, 2002, p. 63).

Due to the complex nature of reflection (Stîngu, 2012) it does not come naturally for a lecturer and as such the process has to be facilitated (Gray, 2007). There are limitations to what will be disclosed, what information can be collected, and the objectivity of the information when lecturers reflect alone (Day, 1998). The benefits of having the assistance of a critical friend or outside expert in enhancing reflection on practice is well documented in literature (Clarke, 1997; Day, 1998; Muir, 2010; Muir & Beswick, 2007).

Gray (2007) suggests the use of a reflection tool such as a reflective framework to facilitate these reflective discourses by acting both as a potential trigger to the reflection, and focusing the reflection. While a reflective framework is useful to get the reflection process started its use is not without criticism. It is argued that the use of a reflective framework may also be very limiting in terms of allowing flexibility and creativity (Bullman, 2004).

3.5 Problematic dimensions of lecturers' reflection

Various problematic areas related to reflection and action in higher education were identified in an empirical study by Mälkki and Lindblom-Ylänne (2012) of which some is discussed in the subsections to follow.

The context-specific relevance of knowledge as motive for reflection

A lecturer's perceptions of the relevance of the knowledge being considered plays a part in whether a lecturer is likely to reflect on it or not (Kreber, 2004), and this perception of relevance is found to be "highly context-specific" (Mälkki & Lindblom-Ylänne, 2012,

p. 43). That is to say, what is perceived as relevant in one context may not be perceived as relevant in another context. Not reflecting on an issue is not necessarily implying the issue is not relevant to the lecturer. It may just be overridden by another issue present in the larger context at that point in time. The context in which reflection takes place consequently has a powerful influence on the motivation for reflection. In the case of this study the knowledge base for reflection, i.e. the use of representations in physics teaching, is generally considered to be very context specific and important and was therefore not seen as something that would be particularly problematic.

Reluctance to move from reflection to action

In order for the reflective process to move from awareness, to acceptance, to action, the barriers to reflection need to be overcome. Some of the barriers mentioned in empirical studies that prevent lecturers from moving from reflection to action are fear of risk taking, lack of experience and knowledge of alternative strategies for teaching, and personal characteristics (McAlpine & Weston, 2002).

Brookfield, as reported by (Mälkki & Lindblom-Ylänne, 2012, p. 36), offered another perspective to the reluctance of practitioners to move from reflection to action by introducing notions of ‘cultural suicide’ (“the risk of being excluded from one’s community as a result of questioning the shared expectations and common understandings pertaining to teaching”), ‘lost innocence’ (the grief experienced of “giving up one’s old beliefs that used to be certain”) and ‘road running’ (“falling back to earlier ways of thinking”). Brookfield furthermore consider the influence of the organisational culture on reflection in either supporting or inhibiting lecturers from engaging in reflection (Mälkki & Lindblom-Ylänne, 2012). Mezirow (1994) further alerts to the fact that reflection may (or may not) lead to change in action. He points out that one has a choice in practice and may decide not to act on a changed belief, or to postpone action. These issues were mentally flagged in this study during the interviews and analysis process.

Problem identification

Academic staff may lack the knowledge needed to pick up teaching and learning events that warrant reflection (McAlpine & Weston, 2002). Problem identification is taken to be the intellectual process of determining what will become the matter or focus for reflection. The identification of teaching problems is problematic in a higher education teaching context and cannot be taken as an automatic process for higher education teachers or lecturers (Akbari, 2007). As Schön (1983, p. 18) states: "professional practice has at least as much to do with finding the problem as with solving the problem found".

He further states that staff development practitioners should not lose sight of the fact that:

> *"... real-world practice problems do not present themselves to the practitioner as given. They must be constructed from the materials of problematic situations, which are puzzling, troubling, and uncertain"*
>
> (Schön, 1983, p. 40).

A trained eye is needed for problem identification (Akbari, 2007); something many lecturers lack based on their traditionally limited educational background and training. Sufficient challenge and support are necessary to scaffold the practitioner towards increasing levels of competence, particularly within the grey and "messy" areas of professional practice in which definitive answers to confronting problems are rarely clear cut.

3.6 Reflection and professional development in higher education

Previous studies done with science lecturers revealed a number of components that are considered effective for professional development activities. These components include engaging the participants in active learning, coherence, a focus on content, duration, and collective participation (Desimone, 2009). These findings hold implications for the development of any solution designed to solve professional development needs, as is the focus of this study. The professional development activities developed during this study would need to engage the lecturers in their own teaching routines and in their own concrete lessons, while the activities they engage in should be centred on a specific topic. This engagement should be sustained and not in a once-off or short-term manner. In addition to the above mentioned effective components identified by Desimone (2009), King (2014) argues for the inclusion of supporting factors such as the guidance by a critical friend or facilitator.

To provide more intensive support for the development and professional learning of lecturers, recent studies successfully included video-based reflections of a lecturer’s own instructional practices (Day, 1998; Powell, 2005; Rosaen et al., 2008; Tripp & Rich, 2012). Using video-stimulated recall to enhance reflection overcome the dependence on the participant’s memory when asked to retrospectively reflect on their practice as required when using for example reflective journals and interviews (Brownhill, 2014; Rosaen et al., 2008; Whitehead & Fitzgerald, 2007). Usually lecturers depend on their own memory of what they think has happened in their classrooms, without objective evidence or documentation (Wong et al., 2006). Video-stimulated reflection allows lecturers to stand back and be 'distant observers' of their practice and be able to consider alternative perspectives in ways that are not possible in a traditional reflection method (Song & Catapano, 2008). They are encouraged to see their instructional practices from a new perspective (Tripp & Rich, 2012).

Henderson, Finkelstein, and Beach (2010) reviewed research literature for approaches to improve the teaching of science in a higher education context and identified the development of reflective lecturers as an important strategy. They furthermore identified various approaches to develop these reflective lecturers as being: by engaging lecturers in staff development sessions with a staff development practitioner; investigations within their own classrooms through action research (Kember & McKay, 1996); developing scholarship of teaching and learning (Kreber, 2005, 2006); involving lecturers in collaborative research in instructional development; and by providing discipline lecturers with information about and tools for research-based instructional approaches (Henderson, 2008). The findings focusing on engaging lecturers through the provision of research-based information, supplemented with tools to assist reflection, while engaging in dialogue as ways of facilitating learning on how to intelligently teach undergraduate students, are of particular relevance to this study. Having actual experience upon which to reflect is essential for turning experience into learning (Boud et al., 1985), which again "may be dependent on the ability to use reflection to recognise patterns in the multiplicity of variables in experiences" (McAlpine & Weston, 2002, p. 63). In other words, "linking knowledge and experience to future action through reflection has the likelihood of improving thinking about teaching and carries a great potential to improve enactment of teaching" (Badara, 2011, p. 33). There are however well documented challenges to overcome when designing professional development activities focusing on the development of reflective practitioners, as have been discussed in section 3.4.

Reflection and epistemological structure

An aspect that deserves mentioning when discussing reflection and professional development in a higher education context, is the relationship between reflective practice and epistemological structure (Donald, 2002). The epistemological structure of a discipline refers to the discipline's culture of thinking and practice; being highly dependent on the discipline in question (Neumann, 2001). Physics is typically viewed as a 'hard pure knowledge' discipline, while engineering is viewed as an 'applied pure knowledge' discipline (Neumann, Parry, & Becher, 2002).

In pure hard knowledge disciplines such as physics, teaching frequently "consists of teacher-oriented sharing of basic knowledge, the main elements of which begin inoculation of the subject content" (Blomster, Venn, & Virtanen, 2014, p. 64; Kreber & Castleden, 2009). This approach to teaching is linked to the perceived nature of knowledge in physics (in the context of this study) where fact-dominated pieces of information need to be taught before the coherent whole can be formed (Neumann et al., 2002). In engineering for example, high regard is given to the development of problem solving skills in which procedures are followed to formulate a problem, do the necessary calculations and verify the logic used to see if the final answer makes sense. However, although the pure hard knowledge disciplines do have a long history of teaching through laboratory courses which provide natural opportunities for the implementation of more student-oriented teaching methods (Blomster et al., 2014), the teaching in these laboratory courses are frequently the responsibility of teaching assistants and not the lecturer responsible for teaching the main classes or lecture part of the course.

In the context of another debate in higher education teaching, namely, the appropriate degree of discipline-specificity and generality in professional development provision, Kreber and Castleden (2009) conducted a study to explore whether academics from various academic (e.g. purse/soft and pure/hard) disciplines engage in reflective practice on teaching, differently. Some of the findings relevant to this study include that disciplines with a more emphasis on quantitative knowledge production are somewhat discouraged to engage in inquiring more formally into core beliefs as well as educational goals and purposes as these are less easily explored through instrumental approaches. Similarly, researchers can expect to be confronted with serious negotiations over what constitutes acceptable evidence in research, and by extension, educational research (Kreber & Castleden, 2009).

Taking cognisance of the above mentioned approached, combined with the barriers identified to implement reflective practice with higher education lecturers, it was decided in this study to focus on the development of a resource that provides physics lecturers with information about and tools to trigger and assist the reflection on their instructional practice. The communication of this resource would involve dedicated, time-conscious training to introduce the resource and offer access to a facilitator when needed. The design and development of this resource is described in Chapter three with the results of the instantiation and evaluation thereof discussed in chapter four.

As the outcome of the implementation of this designed resource is envisaged to be reflection by the physics lecturers, the focus now shifts to literature about the categorisation of reflective practice and thought.

3.7 Categorising reflective thought and practice

Scholars have categorised reflective thought in different ways according to their respective theoretical assumptions. Diversity is again a characteristic, as Finlay (2008, p. 7) so aptly explain: “one of the consequences of the lack of consensus and clarity about the concept of reflective practice is the proliferation of different versions and models to operationalise reflective practice”. Many reflective frameworks are based on stages of the reflective process (Ghaye & Lillyman, 1997; Gibbs, 1988), different levels of reflective thinking or level of cognitive sophistication required during the reflective process (Day, 1998; Goodman, 1984; Kember et al., 2008; Kreber, 2004; Mezirow, 1991; Ryan, 2011) or forms of knowledge for practice (Johns, 2005). A further distinction of importance when characterising reflection, is the distinction between the focus of reflection (the issue or event one reflects upon).

Although the terminology differ, the core concept behind the categorisation of reflection is to provide a description of the degree to which reflection move beyond a mere description or a concern with technical aspects to a critical or dialectical level where practice can be reconstructed (Day, 1999; Fook et al., 2006; Muir & Beswick, 2007) as illustrated with the following examples from literature.

Jay and Johnson (2002) developed a typology that includes three dimensions of reflective thought: descriptive, comparative and critical. Descriptive thought describe the matter for reflection, while comparative reflective thought rephrase the matter for reflection in light of alternative views, others' perspectives, research, etc. Critical reflective thought on the other hand establish a renewed perspective, having considered the implications of the matter (Jay & Johnson, 2002). Similarly, Grossman (2008, reported by Ryan, 2011), suggests at four different levels of reflection along a depth continuum, ranging from descriptive accounts, to different levels of mental processing, to transformative, to intensive reflection, and finally to critical reflection.

Hatton and Smith (1995) do not consider descriptive writing as reflective in nature since no attempt is made to provide reasons or justification for events, whereas the second descriptive level's attempt to provide reasons for events categorise it as being reflective. Both dialogical reflection (a form of discourse with one self-exploring possible reasons) and critical reflection (providing reasons for decisions taking the broader historical, social and political contexts into account) is considered reflective in nature. Larrivee (2008) adapted the above levels by adding fourth level – pre-reflection – based on the argument that reflective practice is frequently contrasted with non-reflective practice in research literature. Larrivee (2008) adopted the terminology of pre-reflection, surface reflection, pedagogical reflection, and critical reflection. Critique against the hierarchical categorisation of reflective levels focussed on the perceived bias towards critical theory (based on critical reflection being positioned as the highest level of reflection) and a negation of practical knowledge and skills (Leijen et al., 2012).

Finlay (2008) distinguishes five types or variants of reflective practice, namely introspection; intersubjective reflection; mutual collaboration; social critique and ironic deconstruction.

Mezirow (1991) distinguishes between three kinds of reflection: reflection on content (focusing on a description of the problem, drawing on what is presently known or believed (Kreber, 2004), process (focusing on the method of problems solving used) and premise (requiring one to reflect on the premises upon which the problem predicated). Bain, Ballantyne, Packer, and Mills (1999) categorised both the levels and the focus of reflection. They identified four foci for reflection in teaching as being the activity undertaken, the self, professional issues and the context in which the activity take place and developed the 5Rs Reflective Writing Scale (reporting, responding, relating, reasoning, and reconstructing) to describe the level of reflection displayed in reflective writing. Kember et al’s (2000) levels of reflection include habitual thinking; understanding or thoughtful action; reflection; and critical reflection. Similarly Jay and Johnson (2002), Moon (2008) and Van Manen (1977) identify levels of reflection moving from simple description to judgments and finally a willingness to explore alternative perspectives, theorise, analyse, and seek a deep understanding.

Although reflective practitioners are warned by fellow theorists to guard against the technical application of frameworks to focus the reflection, a framework is essential to structure thinking and supporting the reflective practitioner to make sense of material gathered during reflective process. See for example Johns’ (2002) Model for Structured Reflection in a nursing education context. Johns’ model gives prompts for reflection that enable progression of thought in what he sees as a reflective spiral (not a hierarchy) that moves the practitioner from a “perception [of] what lies on the surface of the experience and what may seem obvious, to insights that lie enfolded within” (Johns, 2009, p. 52). He agrees with Korthagen and Vasalos (2005) that structured reflection promotes sound professional behaviour and the development of ‘growth competence’ namely the ability to continue to develop professionally on the basis of internally directed learning (Korthagen, Kessels, Koster, Lagerwerf, & Wubbels, 2001).

In the light of the vast amount of literature on reflection, an attempt has to be made to operationalise the concepts reflective thought and practice in such a manner that it is both theory-based, but also relevant to the study. The focus of this study is on the reflective thinking of lecturers as response to the use of a framework to stimulate their reflection about the instructional affordance of their use of representations during their introductory physics classes. As such the reflective practice theoretical framework to be used in the analytical activities of this research (see Chapter three) require a specific 'feel'. Also, it was intended that the measuring instrument should not be too fine grained to allow someone without detailed knowledge of the literature on which the categories were based, to apply the framework.

The various categories of reflective thought and practice described in literature and alluded to in the discussion above, were taken in consideration to develop the theoretical framework used in this study (described in Table 2.1). The Structured Observed Learning Outcomes (SOLO) taxonomy of Biggs and Collis (1982) describes levels of increasing complexity in students' understanding. This taxonomy was used in conjunction with the categories of reflective thought and practice identified in research literature to develop a taxonomy describing the expected reflective action(s) of physics lecturers reflecting on their instructional practice.

In summary, different conceptions and models of reflective practice continue to emerge across different professional groups as the demand for more thoughtful, reflexive and critical reflective practices increase. However, this phenomenon also has a dark side where, if applied unthinkingly, reflective practice can become mechanical (Finlay, 2008). The bottom line is that reflection is “a complex, rigorous, intellectual, and emotional enterprise” (Rodgers, 2002, p. 845) and as such “models need to be applied selectively, purposefully, flexibly and judiciously” to allow professional practice to benefit from the multiple models and competing perspectives (Finlay, 2008, p. 10).

Table 2.1: Levels of reflective practice adapted to the context of reflection on higher education instructional practice

SOLO category	Reflection category	Description/Criteria for the recognition of evidence	
Extended abstract Making connections within given subject area & beyond. Able to generalise & transfer principles & ideas underlying the instance	**Reconstructing** (Bain, Ballantyne, Mills, & Lester, 2002)	**Dialectical.** Demonstrates awareness that actions and events are not only located in and explicable by reference to multiple perspectives, but are located in and influenced by multiple historical and socio-political contexts. Evidence of transformation of perspective. See assumptions, methods, beliefs and practices of one's profession as problematic (Hatton & Smith, 1995; Power, Clarke, & Hine, 2002). Link both depth (the process with increasing levels of argumentation e.g. describing, justifying, evaluating, discussion) and breadth (Thompson & Thompson, 2008). Participant moves beyond identifying 'critical incidents' and providing explanations to considering others' perspectives and offering alternatives (Muir & Beswick, 2007). **Premise reflection** – helps understand motivations & assumptions that underpin experiences. Provides reflection on values & beliefs. Promotes expansion of meaning perspectives (Cox, 2013; Mezirow, 1991).	**Now what?**
	Reasoning (Bain et al., 2002)	**Dialogical reflection** (deliberative; cognitive & narrative) (Muir & Beswick, 2007). Concerned with weighing competing claims and viewpoints, and then exploring alternative solutions (Hatton & Smith, 1995; Power et al., 2002). Identifies 'critical incidents' & offers rationale or explanation of action or behaviour. Demonstrates a 'stepping back' from the events/actions leading to a different level of reflection (Moon, 2004). Discourse with self & exploring the experience, events and actions using qualities of judgements and possible alternatives for explaining & hypothesizing. Concerned with reflection in action & contextualisation of multiple viewpoints (Hatton & Smith, 1995; Power et al., 2002). **Process reflection** – encourage active self-monitoring and aids metacognitive abilities (Cox, 2013). Reflection on the problem solving method used Mezirow (1991).	**So what? Theory and knowledge building**

SOLO category	Reflection category	Description/Criteria for the recognition of evidence	
Relational Appreciate significance of the parts in relation to whole	**Relating** (Bain et al., 2002)	**Content reflection** – full portrayal of events & experiences in terms of content taught. Enable identification of patterns & general principles in relation to ways content is described (Cox, 2013; Mezirow, 1991). Take a concept and considers it in relation to personal experiences attaching personal meaning to the concept that goes beyond book theory. Theory and knowledge building. Reflection based on the recognition of multiple factors and perspectives.	
Multi-structural A number of connections are made but meta-connections between them are missing **Uni-structural** Simple & obvious connections are made, but significance not grasped	**Responding** (Bain et al., 2002)	Concepts are understood as theory, but not related to personal experiences or real-life applications. Since theoretical concepts have no personal meaning they may not be assimilated in an individual's knowledge system/structure. Some evidence of thoughtful action. Some attempt to provide reason justification for events or actions but in reportive or descriptive way. Reflection based generally on one perspective/factor as rationale. Considered to be surface reflection (Larrivee, 2008).	
Pre-structural Unconnected information	**Reporting** (Bain et al., 2002)	**Technical rationality** (addressing task and self-concerns) (Hatton & Smith, 1995; Power et al., 2002). Evidence of habitual action with some evidence of thoughtful action, but understanding is truncated. Little thought given to applicability of strategies or alternatives. No attempt to reach an understanding of the concept or theory that underpins the topic. Non- reflective description of event or report of literature. No attempt to provide reasons/justification for events. Considered to be at a pre-reflection level (Larrivee, 2008).	**What? Descriptive**

Shaded area: Non-reflective actions based on work of Mezirow (1991).

4. SOCIAL SEMIOTICS AND AFFORDANCES

Grotzer (2013), amongst many others, argues that learning in science is considered to involve a process of constructing meaning. Research on this meaning-making process of learning has been framed in either cognitive or socio-cultural accounts of interactions between learners, resources and contexts (Prain & Tytler, 2013). The cognitive accounts focus on individual learners' mental strategies in engaging with these material and symbolic tools how learners develop mental models, schemas, organising strategies and frameworks to learn from interacting with these tools (Prain & Tytler, 2012, p. 2754). Cognitive theories such as dual coding theory and cognitive flexibility theory can explain why the use of multiple external representations are beneficial to learning, but Wu and Puntambekar (2012) emphasise that they do not provide much information on pedagogical issues. Socio-cultural accounts on the other hand focus on the guided meaningful practice in using the material and symbolic tools with their application as a key driver of collective learning [and subsequently teaching] in the classroom (Airey & Linder, 2009a; Jaipal, 2010; Prain & Tytler, 2012; Prain & Waldrip, 2006).

The multimodal based theories of constructing meaning in science, namely social semiotic theory, affordance theory and disciplinary discourse (Airey & Linder, 2009a; Prain & Waldrip, 2006), consequently form the second part of the theoretical framework of the study. But, as been pointed out by Matthews (2002), there is not necessarily any simple, coherent link between theories of learning and appropriate pedagogy. Similarly it is advisable to remember that there is not necessarily any simple, coherent link between theories of learning with and from representations and the appropriate instructional use of representations by lecturers. In the section to follow a theoretical framework for the instructional use of representations is proposed, namely a social-semiotic perspective on the use of representations by lecturers as part of their classroom disciplinary discourse.

4.1 Social semiotics – a meaning making process

Semiotics is a language-based theory that can be used to gain insight into the meaning potential of semiotic signs used in communication. In the field of semiotics, a system of semiotic resources (traditionally called ‘signs’) allows individuals to share and refine their ways of knowing or representing disciplinary knowledge (Van Leeuwen, 2005). From a social semiotic perspective, the aim is to explain how we make meanings with all the semiotic resources at our disposal: linguistic, pictorial, gestural, musical, choreographic, and mostly actional (Lemke, 1990). Semiotic resources are seen as the realisation of meanings (Kress, 2010); symbolic tools and signs that resultantly mediate both the social and individual human action (Wertsch, 1991).

Intentionally produced signs are generally used for communication. This implies that “all our communication, all of how we share ways of knowing, figuring and doing – is constituted through the two aspects of communication, namely the production and the interpretation of semiotic resources” (Fredlund, 2013, p. 19). For example, a teacher can produce a series of utterances or a diagram in order to convey knowledge about something (the represented content) to a recipient. In other words, a teacher has something in mind about a content to be represented, and the teacher expresses this view about the content by producing a sign. Learning is understood as students developing the capacity to “recognise and use key functional features of generic and science-specific material and symbolic tools to construct an account of phenomena” (Prain & Tytler, 2012, p. 2755). All communication of knowledge is consequently seen as taking place through a variety of semiotic modalities (or signs) (Jaipal, 2010) that include aspects such as “speech; still image; moving image; writing; gesture; music; 3D models; action; [and] colour” (Kress, 2010, p. 28).

The term *mode* appears to be used interchangeably with the term *semiotic resource* in literature. This requires clarification of the use of the concept of modality in the context of this study. The concept ‘multimodality’ is taken as meaning “a multiplicity of different kinds of semiotic resources, in other words, written and spoken language, mathematical formalism, gestures, pictures, diagrams and so on” constituting a multimodal text (Fredlund, 2013, p. 20).

Semiotics and science

Natural science is a discourse about the materiality of the world, using a system of independent social semiotic practices and activities of various kinds, united by various discourses (Lemke, 1990). Science can thus be seen as a knowledge system of signed information (Danesi, 2007) known as the “semiotic knowledge system” of science, which “encompasses theories, symbolic generalisations/laws (e.g., F = ma), tools (e.g., constant proposition), models (e.g., force fields), methods (e.g., careful observations), processes (e.g., deductive experiments), and shared norms and values” and acts as a frame of reference for the interpretation of signs (Jaipal, 2011, p. 195). Understanding scientific meanings thus depend on the reader being able to interpret the different semiotic modalities by looking at how multiple signs interact with each other and how multiple signs together communicate the meaning of the content (Jaipal, 2011).

Representations, meaning, and representational conventions

Moving to a physics context, representations are constructed from collections of signs that get their intended meaning from "the ways that the physics community uses the representations to produce, interpret, evaluate and share meaning" (Lemke, 1990, p. 43). External representations are resultantly used to convey some meaning (Demetriadis et al., 2004), but it is also believed that graphs, pictures, etc. do not constitute a representation by themselves (Greeno & Hall, 1997). Before a notation can function as a representation, someone has to interpret it and thereby give it meaning (Greeno & Hall, 1997; Janvier et al., 1993). For example, a mathematical representation only makes sense as part of a wider system within which meanings and conventions have been established (Goldin & Shteingold, 2001). The "set of meanings that a semiotic resource can convey is called its meaning potential" (Fredlund, 2013, p. 21). The meaning of multimodal text is however context dependent. "Different aspects of these meaning potentials can be (and often should be) differently realised in different contexts" (Fredlund, 2013, p. 21). As explained by Fredlund: By raising the thumb and curling the fingers you may be asking for a lift in one context, or you may be illustrating the right hand rule (in another context). "In the production of a semiotic resource [raising your thumb] the intent is to realise some essential part of the meaning potential of that semiotic resource" in a particular context (to hitch a ride) (Fredlund, 2013, p. 21).

Meaning making is seen as the process of interpreting the representation according to a particular code– a series of conventions for depicting the relations in the represented display (Gilbert, 2008). Equations, graphs and tables are considered to be standard forms of representations that frequently have shared conventions or codes of interpretation (Greeno & Hall, 1997) or a series of conventions for depicting the relations in the represented display (Gilbert, 2008). "In the context of the teaching and learning of a science such as physics, the meaning-making potentials of representations need to be well understood in order for them to be used in optimal ways" (Linder, 2013, p. 43). It is consequently the lecturer's goal to provide semiotic mediation, described by Van de Walle, Karp, and Bay-Williams (2010, p. 21) "as involving social interaction through language as well as through diagrams, pictures, and other non-textual tools of mediation to assist the students with this meaning making process". Teaching therefore can mean assisting the students with:

> *"learn[ing] the conventions of interpretation of standard representational forms at an operational level. ... In these activities students can learn to follow the standards of conventions of interpretation for the [representational] forms, and with this learning the forms function as representations for the students"*
>
> (Greeno & Hall, 1997, p. 366).

It has been shown, however, that many dimensions of these disciplinary ways of knowing are often taken for granted by lecturers in their instructional practice (Middendorf & Pace, 2004). Northedge (2002) believes

> *"university lecturers often do not fully appreciate ... the sociocultural groundings of meaning. Their thoughts are so deeply rooted in specialist discourse that they are unaware that meanings they take for granted are simply not construable from outside the discourse".*
>
> (Northedge, 2002, p. 256)

In a similar vein, Geisler (1994) claims texts, like other objects of expert knowledge, appear

> *"to afford and sustain both expert and naïve representations: the expert representation available to insiders to the academic professions and the naïve representation available to those outside".*
>
> (Geisler, 1994, pp. xi-xii)

It has been argued by a number of authors that problems in student learning are largely a function of difficulties in handling and understanding highly specialized forms of communication that are not frequently found in everyday situations (Driver & Erickson, 1983).

4.2 Affordance theory and representations

Another construct of use when discussing the meaning potential provided by different semiotic resources is that of 'affordance'. An affordance describes the potential for meaning making embedded in a semiotic resource by providing cues to the meaning potential embedded in the resource.

The concept of affordance

Affordance is a conceptual term derived from the work of Gibson and Norman (Prain & Tytler, 2013). Affordance theory states that the world is perceived not only in terms of object shapes and spatial relationships but also in terms of its possibilities for action (affordances). Gibson argued that individuals interact with the physical environment in terms of affordances that support their goals or intentions. As such, Gibson argued that affordances have inherent meaning, for example, the inherent properties of an apple afford it to be eaten (Jones, 2003). Gibson's view that affordance is linked to an object's inherent properties has been criticised as it fails to explain how a person assigns meaning to what they see and in the process decide whether to perform an action or not (see e.g. Airey, Eriksson, Fredlund, & Linder, 2014). This lead to the introduction of the concept 'perceived affordance' by Norman (1999).

Norman described affordances as perceived affordances in that the enabling feature in the environment needs to be noticed by the individual to be enabling; the individual has to recognise a required potential action that the environment both prompts, as well as supports (cited in Prain & Tytler, 2013). Norman's (1999) interpretation situates an affordance within a relationship between an artefact and the user, referring to the perceived affordances as the perceived properties of artefacts that determine how the artefact can be used. If the user directly recognises the meaning of an object, the affordance can be labelled as a 'simple affordance' (Turner, 2005). In contrast to simple affordances, complex affordances depend on the specific capabilities of the user who internally creates meaning of the artefact by processing additional information. Complex affordances encompass history and practice (Turner, 2005).

It can be concluded that perceived affordances offered by the environment need to be appropriated by a person in order for it to provide the individual with opportunities for action. Appropriation of affordances refers to the intentional utilisation of the affordances for action taking (Vatrapu, 2007). Of importance in the context of education is the idea that the appropriation of affordances are learned rather than developed through direct perception. For example, for a person to perceive a cup as a container for various liquids and solids depends upon prior knowledge that can only be acquired through learning rather than direct perception. Turner (2005) notes that although the affordance of the object exists whether it is perceived or used, it only comes available when it fits in with the users' requirements or goal and are then perceived by them. Examples of such affordances include: buttons for pushing, knobs for turning, handles for pulling, levers for sliding, etc. (Prain & Tytler, 2013). If the button for example is not being perceived as meaning something or providing the possibility for action, the button may still exist, but it will not afford or enable action. The perception of affordance thus depend on the goals, expectations, knowledge, skills and cultures of the person who perceive the affordance and consequently is culture-sensitive, context-dependent and tool-specific (McGenere & Ho, 2000).

The learning of affordances depend on the ease with which the user perceive an affordance (exiting capabilities) and the clarity of the information the affordance carry (McGenere & Ho, 2000). Through practice, people learn how to associate the artefacts in their environment and the perceived outcome in order to conduct an action. Expertise in perception of affordance is therefore developed through practice.

Affordance and external representations

The concept of perceived affordances is of importance in the context of physics education and the instructional use of external representations in particular. External representations (in the Gibsonian ecological approach) can be taken as embodied environmental information that can be directly picked up by the human perceptual systems (Vatrapu, 2007) and as such they can act as perceived affordances. This view is reflected in Zhang's (1997) definition of external representations as:

> *"… the knowledge and structure in the environment, as physical symbols, objects, or dimensions (e.g., written symbols, beads of abacuses, dimensions of a graph, etc.), and as external rules, constraints, or relations embedded in physical configurations (e.g., spatial relations of written digits, visual and spatial layouts of diagrams, physical constraints in abacuses, etc.)"*
>
> (Zhang, 1997, p. 180).

The role played by the different external representations in the sharing of knowledge is determined by their affordances (Fredlund, Airey, & Linder, 2012). Images, for example, afford the sharing of spatial and directional relationships (Kress & van Leeuwen, 1996). Human cognition can therefore be characterised as collective appropriation of affordances (Hodges, 2007).

Disciplinary affordance

Individual representations can therefore have their own (unique, supplementary or complementary) affordances (Ainsworth, 1999). Building on Lemke and others, (Kress, 2010) suggested the focus move from the affordance of an individual object (e.g. picture, diagram) to the affordance of a mode focusing on the different communication potential of modes. Each of these modes is seen as having different affordances or "different possibilities for representing disciplinary ways of knowing" (Airey & Linder, 2006, p. 4). Fredlund et al. (2012) extended the idea to include the concept of a representation's disciplinary affordances, defining it as:

> *"… the inherent potential of that representation to provide access to disciplinary knowledge. Thus, it is these disciplinary affordances that enable certain representations to become legitimate within a discipline such as physics. Physics*

learning then, involves coming to appreciate the disciplinary affordances of representations"

(Fredlund et al., 2012, p. 658, emphasis added).

This leads to defining the discipline's "collective disciplinary affordance" as "[a] set of carefully selected multimodal representations, each with their own (unique, supplementary or complementary) affordances", together constituting the collective disciplinary affordance (Linder, 2013, p. 47). Being aware of the discipline's collective disciplinary affordance provides lecturers with the possibility to choose a constellation of representations that offers the best set of affordances for the situation at hand (Airey & Linder, 2009a). Figure 2.1 provides an illustration of such a critical constellation of representations in a kinematic setting (Van Heuvelen, 2001).

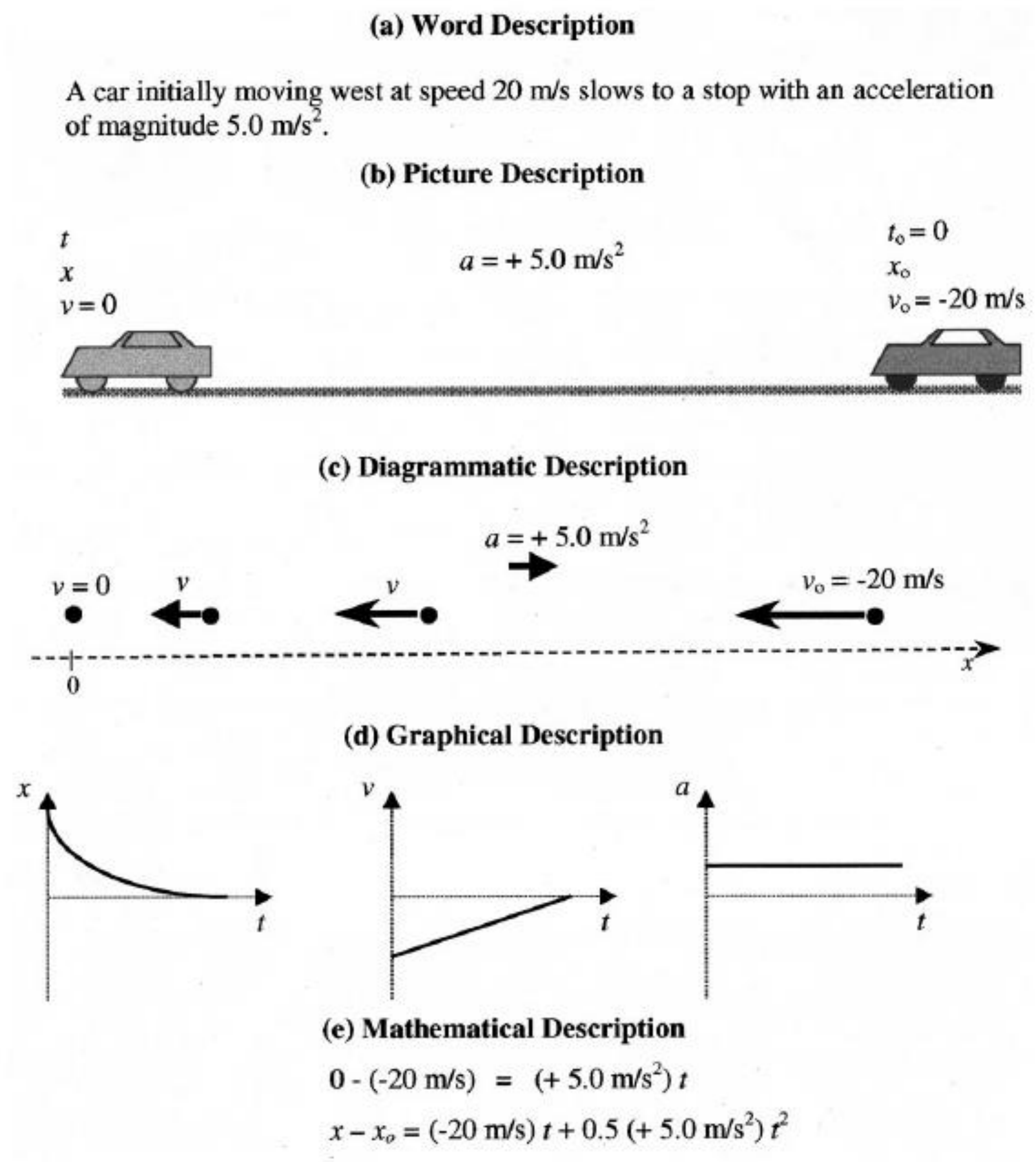


Figure 2.1: An illustration of a critical set of modes of representation for a collective disciplinary affordance for the given kind of kinematic setting (Van Heuvelen, 2001, p. 1142).

A further aspect of disciplinary affordance relevant to physics education is the ability to not only see the affordance of a particular representation mode, but also what affordance lies behind the presented representation mode known as the "appresentation of an affordance" (Linder, 2013, p. 47). A person who has achieved fluency in the disciplinary discourse of physics is able to see the affordance attributes that are both presented and appresented in the representation (Linder, 2013).

Pedagogical affordance and instructional affordance

Norman's (1999) description of affordances as perceptual interactions with the environment was extended by Prain and Tytler (2013) to include learnt behaviour and strategies in the classroom. This is particularly relevant to physics education in the light of the multimodal nature of science communication where a diverse set of semiotic resources, for example language, images, 3-D models, and mathematical symbols are used in its communication to allow the science lecturer to communicate different aspects of the discipline (affordances). As the focus of this study is on the lecturer in the classroom, it is necessary to distinguish between pedagogical affordances and instructional affordances. Healey, in an article written in 2000, distinguished between pedagogical knowledge as referring to what we know about how students learn, and instructional knowledge as meaning knowledge that teachers need to acquire in the area of instructional design (Healey, 2000). The focus of pedagogical knowledge can be thought of as being on the students and their learning, while the emphasis in instructional knowledge seems to be on the act of teaching, more than the act of learning.

Ainsworth (1999) established that lecturers use representations in the teaching of physics because it affords them certain pedagogical functions, labelling these functions as representing pedagogical affordances. Using the ideas behind the concepts pedagogical affordance (Ainsworth, 1999) and disciplinary affordance (Fredlund et al., 2012) combined with the distinction made between pedagogical and instructional knowledge (Healey, 2000), leads to the perception of the concept 'instructional affordance' with the emphasis on the affordance or constraints offered for teaching a subject. Instructional affordance will differ from pedagogical affordances in terms of focus. The focus of pedagogical affordances is on the affordances or constraints for learning a subject. This leads the way to thinking about the signification of the representations used in a physics classroom in terms of their instructional affordances (or constraints). Different representations can be argued to offer different instructional affordances to a lecturer – they are selected to do different work in the teaching of physics concepts.

Instructional affordance and instructional disciplinary discourse

In order for lecturers to select the most appropriate representations from a wide range of modalities to achieve the desired affordance (or constraint), competent lecturers require a special type of knowledge, namely pedagogical content knowledge (Shulman, 1998), which includes a form of discourse that is unique to the teaching of the discipline. Pedagogical content knowledge also depends on having previous experiences implementing the various representations in science classrooms. Research shows that one factor, among others, affecting how modalities are selected, is teachers' views of the subject, teaching and learning (Shulman, 1998).

It is important to remember that while the types of signs or semiotic modalities used by scientists to represent scientific knowledge may be similar to what a science lecturer uses in classroom during instruction, the purpose for which the representations are used is different. The purpose is not just for the communication of the disciplinary semiotic resources used in the practice of physics, but more importantly to afford the lecturer opportunities to use these semiotic resources in such a manner that they enable the achievement of educational goals.

This unique discourse with its purpose of teaching in a discipline, can be called instructional disciplinary discourse, taken as being the complex of activities, representations and tools used during the instruction of a discipline (c.f. Airey and Linder's (2009a) concept of disciplinary discourse). Instructional disciplinary discourse can be seen as being made up of various modes: spoken/written language, mathematics, gestures, images, tools and activities – but with the specific focus of using these semiotic resources afforded by each of these modes to enhance students meaning making and understanding in the discipline in an instructional context.

4.3 Implications of affordance in the context of design-based research

The focus of this research is on designing an artefact that would contribute to resolving the research problem of promoting physics lecturers' reflections on their instructional use of representations. It is therefore necessary to align the research problem, the approach chosen to solve the problem, and the theoretical framework in which both the problem and the solution is grounded. This necessitates a consideration of the implications of affordance to the research process. Norman's (1999) ideas around affordances were extended to make them more applicable to the context of design-based research. McGenere and Ho (2000) argue for a separation of the affordance from the perception of the affordance to allow researchers to distinguish more clearly between the utility of an artefact (an affordance) and designing usability (the information that specifies the affordance).

Hartson (2003) differentiates between affordances reflecting the role they play during the performance of a task. He identified cognitive affordances as symbols, constraints and conventions as underlying mechanisms that help the user in knowing, while physical affordances help users to conduct a physical activity. Hartson introduced sensory affordances as properties of the stimuli the user perceives and explain that sensory affordance play a support role for cognitive and physical affordances. “Sensing cognitive affordances is essential for their [users’] understanding, and sensing physical affordances is essential for acting upon them” (Hartson, 2003, p. 322). The forth type of affordance relates to the functionality of a feature and affords users “access to a certain application feature or functionality” (Hartson, 2003, p. 323).

When developing an artefact that aims at engaging the user in a particular action (as is the case in this study) it is important to keep both physical properties and the perceived affordances in mind.

5. INSTRUCTIONAL USE OF REPRESENTATIONS

In order to develop a framework for the instructional use of representations, the section to follow will review conceptual and descriptive empirical research on teaching introductory physics at university level with a specific focus on the use of representations during instructional practice. While there is a large body of knowledge related to learning with and from representations in physics, as well as on using representations to solve problems, this study focuses on the instructional use of representations. Also, while there is a body of knowledge describing the disciplinary use of representations in physics, the focus in this study is on the instructional affordance and meaning-making of representations in the context of the introductory physics classroom.

5.1 Multiple representations

As mentioned earlier, external representations are developed and used with the purpose of conveying meaning (Demetriadis et al., 2004) where meaning making involves the process of interpreting the representation according to a particular code (Greeno & Hall, 1997). This code refers to the specific expressive formats in which information is displayed (e.g. pictorial, symbolic, textual) and can either be “descriptive (a system of signs for constructing descriptions of real world, such as natural language) or depictive (a code that depicts reality by analogy, such as images and graphics)” (Demetriadis et al., 2004, p. 12). The importance of the use of multiple representations has been recognised to the extent that “it has been suggested that competency with several representations of a concept is a prerequisite for expert-like understanding” (Kohl et al., 2007b, p. 1). The National Council of Teachers of Mathematics (2000, p. 206) has noted that if multiple representations are carefully applied, they "fulfil a dual role: they are tools for thinking and instruments for communicating". This study focuses on the communicative or semiotic role of multiple representations as illustrated by Demetriadis et al. (2004). In the context of learning environment Demetriadis et al. (2004, p. 12) argue that a representational code and a specific modality is used to develop a meaningful message for learning where meaning “refers to the ability of the ‘receiver’ of the representation to efficiently decode the structural relationship that the representation conveys and connect it to previous knowledge”.

Multiple representations refer to the representation of a physical phenomenon using different forms of representation (e.g. graphical and mathematical) or different versions of a representation (e.g. graphs showing speed and acceleration as functions of time) (Kohl et al., 2007b). Prain and Waldrip (2006, p. 1844) consider multiple representations to be “the practice of re-representing the same concept through different forms, including verbal, graphic, and numerical modes, as well as repeated student exposures to the same concept". The different forms of representations (such as real world, manipulatives, pictures, spoken symbols and written symbols) contribute differently to conceptual understanding (Van Heuvelen & Zou, 2001), problem solving, and decision processes by highlighting some attributes over the others (Kleinmuntz & Schkade, 1993; Zhang, 1997) compared to a single (or isolated) representation that cannot address all of these sub-constructs substantially.

A related, but not equivalent concept is that of multimodal representations. The concept multimodality is used differently depending on whether the focus of the researchers are on the semiotic level (referring to the representational format used such as texts, pictures and sounds) or on the sensory level (focusing on the sensory modality of sign reception, e.g. visual, auditory and tactile modality) (Schnotz & Lowe, 2003). This study focuses on the semiotic level of representational use and as such the definition for multimodal representation proposed by Prain and Waldrip (2006) is of relevance. Multimodal representation is about representing knowledge in different language forms, e.g. graphical, mathematical, pictorial and textual representations to represent an idea, show reasoning, or provide an explanation (Prain & Waldrip, 2006). A multiple representation therefore integrates and displays more than one representation of the same object or idea (Kohl, 2007).

The explanatory power and limitations of multiple representations

A substantial portion of research on multiple representations has focused on how the use of more than one representation affects student understanding (see e.g. Ainsworth, 2006, 2008; Airey & Linder, 2006; Kohl & Finkelstein, 2007; Prain & Tytler, 2013), helping students develop images that give meaning to mathematical symbols (Escalada & Zollman, 1997), catering for various learning styles (Ainsworth, 1999), and developing expertise in the possession and coordinated use of multiple representations (De Jong et al., 1998).

Multiple representations resultantly support learning and communication by allowing complementary information or processes to be communicated, constraining the interpretation of one representation by using one representation to constrain the interpretations in the use of another new representation, or allowing for the construction of more complete understanding of a situation (Ainsworth, 1999, 2008). The main argument proposed by this growing body of research is that different representations have different affordances (potential for communication) and as such play a variety of roles in the sharing of knowledge (Prain & Tytler, 2013). Given the vast variety of information to be conveyed in a complete set of learning materials, this would require several types of representations. Furthermore, De Jong et al. (1998) argue that information that is specific for a certain topic should be displayed in a format that is best suited for that topic, hence in a specific representation.

Unfortunately there is considerable evidence to show that students often fail to utilise the advantages or affordances offered by multiple representations (Ainsworth, 2008). “A representation is only useful if it can be ‘grasped’ by the student” (Van Garderen, 2007, p. 541). Kohl et al. (2007b) found that the use of multiple representations alone is insufficient for success. In the worse cases inappropriate combinations of representations can completely inhibit learning - the correct use of multiple representations is required for success. It can be concluded that “multiple representations are powerful tools to help learners develop complex scientific knowledge", but "they require careful handling and often considerable experience before people can use them to their maximum effectiveness" (Ainsworth, 2008, p. 12).

The relationship among representations

An issue widely discussed in the physics education literature around the use of multiple representations is that of the connections or translations between representations (the process of transferring information from one given representation to fit other comparable descriptions) (Ainsworth, 2006; Lesh, Post, & Behr, 1987b; Van der Meij & de Jong, 2006) being it "between different representation forms of the same mathematical idea or between related ideas within the same representation form" (Hiebert & Carpenter, 1992, p. 66). This ability to connect various representations play a particular role in learning with understanding (Hiebert & Carpenter, 1992). It is however important to take note that translation between coordinated representations of the same phenomenon is not automatic (Ainsworth, 1999). Gilbert (2008) suggested that this well-established obstacle results from each representation type's distinct code of interpretation – a series of conventions for depicting the relations in the represented display. Research done in the area of multiple representation designing has proposed that the sequence in which representations are introduced can affect learning outcomes (e.g., Ainsworth, 2006).

Wu and Puntambekar (2012, p. 761) identified a variety of approaches to scaffold students' learning with representations "… such as implicit cues (e.g., consistent labelling), integrated representations (e.g., merging representations or presenting them close to each other rather than separately), static linking (e.g., clicking on one part of a representation and highlighting corresponding parts of other representations), [and] dynamic linking". van der Meij and de Jong (2006) distinguish between static and dynamic linking by pointing out that dynamic linking involves the use of technology "… to link representations in such a way that changes in one representation result in changes in all connected representations." Wu and Puntambekar (2012, p. 761) also note that making affordances of multiple external representations explicit and modelling how to make translations between multiple external representations enables model progression. Model progression entails making the links between representations explicit by means of a sequence of presentations that move progressively towards more abstract or schematic use of presentations. These approaches may all contribute to addressing students' difficulties (Ainsworth, 2006).

5.2 Taxonomy of representations relevant to this study

A study of representational literature reveals numerous strategies to categorise and classify representations, with several frameworks or taxonomies proposed, serving a variety of research purposes. For example, Prain and Waldrip (2006) categorize representations into descriptive (verbal, graphic, tabular), figurative (pictorial, analogous and metaphoric), mathematical, experimental, and kinesthetic or embodied gestural representations, while the use of representation characteristics such as sensory channels, modalities, and levels of abstraction lead to categories such as auditory/visual, textual/ graphical, abstract/concrete, and so on.

Majidi (2013) distinguishes seven modes of representation, namely descriptive, explanatory mathematical, visual, a statement of fact, an experiment and reasoning. Descriptive and explanatory mathematical models connect conceptual elements through mathematical relations or equations. However, a descriptive model is applied to define new laws or concepts, while an explanatory one explains the applications or examples of already-defined laws. Visual representations help with the visualization of different conceptual or complex elements of scientific phenomena which are often hidden from their direct observation or experience and may be classified from most abstract to least abstract representations (equations, graphs and tables, maps and diagrams, naturalistic and schematic drawings, and photographs) (Liu & Treagust, 2013). Liu, Won, and Treagust (2014) used a classification proposed by Hegarty et al. (1991) to describe iconic drawings as realistic pictures or drawings of concrete objects, whereas, schematic drawings are more abstract representations such as an electric circuit diagram. Charts and graphs present the relationship between quantitative data. A statement of fact concerns declarative knowledge and describes a given set of facts. An experiment provides information about an observation, discoveries, and phenomena. Reasoning is a mode of presentation which can be considered a model that provides reasons or arguments to justify the connections between conceptual elements, while an analogy is seen from the perspective of mapping between similar conceptual elements (Majidi, 2013).

Lemke (1998) and Tsui (2003) proposed a taxonomy that includes four major types of representations: verbal-textual, symbolic-mathematical, visual-graphical, and actional-operational. Lemke proposed the taxonomy to analyse scientific texts in physics and Tsui revised the taxonomy for use in biology education. Guttersrud and Angell (2008) added to the taxonomy proposed by Lemke and Tsui by developing an analytical framework based on five representation forms, namely mathematical, graphical, pictorial, conceptual. However, as Ainsworth (2006, p. 190) indicated, ‘‘although there is some overlap between the taxonomies, no one classification is universally accepted’’. In this study a combination of Lemke, Tsui and Guttersrund and Angell’s models was used as the analytical framework to classify the types of external representations observerable in the instructional practice of a lecturer (see Table 2.2).

Table 2.2: Modes of representations (adapted from Oh & Kim, 2013)

Mode of representation	**Description**		**Examples**
Verbal – textual	This mode is characterised by the use of natural language in pedagogically transforming subject matter knowledge (Oh & Kim, 2013). The use of symbols to express abstract knowledge such as conveying information about conceptual relations and logical sequences (Schnotz, 2005). The verbal mode usually accompanies the use of a representation in many of the other modes. The verbal mode is subdivided into spoken and written modes.	Spoken	Statement of Facts Real-life example Analogy Metaphors Reasoning (provide reasons or arguments to justify connections between conceptual elements)
		Written	Notes Written problems Textual table
Pictorial / Visual-graphical	In the visual-graphic mode, such two-dimensional visual representations as pictures and diagrams are used to help visualise different conceptual elements. Visual-graphical representations are informationally complete – used when drawing inferences (Schnotz, 2005). Visual resources have an organisational function (Lemke, 2007). The visual mode is subcategorised into static and dynamic modes.	Static	Photographs Diagram Map Sketch Drawing Abstract graph Textual table
		Dynamic	Real-life example Animation Real-time graphs

Mode of representation	**Description**		**Examples**
Symbolic mathematical	In this mode, mathematical symbols and expressions are used to connect conceptual elements through mathematical relations or equations. This mode can be subcategorised as either descriptive or explanatory.	Descriptive (define new laws or concepts)	Numerical table Equation $V = m^3$ Formula $F = ma$
		Explanatory (explain applications or examples of already defined laws)	Numerical table Equation $V = m^3$ Formula $F = ma$
Actional operational	This mode is characterised by the movement of a human body or parts of it to represent subject matter knowledge.		Hand gestures Hand demonstration
Material	This mode is characterised by the use of 3D materials to represent subject matter knowledge. The material mode is subdivided into static and dynamic modes.	Static	Concrete physical model
		Dynamic	Real-life example Science demonstration
Complex	In this mode, more than one semiotic mode is used to represent a single target of knowledge.		Video Flash animation Real-life Experiment Role play

5.3 Implications for physics instructional practice

There is a growing recognition that "students need to learn how to interpret and construct representations of science concepts, processes, claims and findings, where representing entails both the processes of coming to know in this subject as well as what is known" (Prain & Tytler, 2013, p. 3). Instruction is always in need of appropriate representations for presenting the content to be learned (Demetriadis et al., 2004).

Developing disciplinary and representational literacy

The implicit aim of introductory physics is to develop students' disciplinary literacy (Nichols, Hanan, & Ranasinghe, 2013). Airey define disciplinary literacy as "the ability to appropriately participate in the communicative practices of a discipline" (Airey, 2009, p. 1). Prain and Waldrip (2010) identify three elements of disciplinary literacy namely, (i) the indicative language practices (e.g. verbal. visual and mathematical) of science discourse, (ii) comprehension of the functions of these literacies in representing science processes and (iii) are fundamental tools for meaning-making and knowledge building. The communicative practices of physics education is characterised by multimodality (Gilbert, 2005) where a diverse set of semiotic resources are used, for example written and spoken language, images, 3-D models, and mathematical symbols (Airey, 2009). Each of these modalities have different disciplinary affordances, that is, they perform different disciplinary work (Fredlund et al., 2012). These semiotic resources can be equated to the 'semiotic knowledge system' of science as described in section 4.1, or as conceptualised by Airey and Linder (2006) as the disciplinary discourse.

For lecturers to develop students' ability to develop disciplinary literacy and use it effectively to construct knowledge of complex scientific phenomena, they need to (i) view learning in physics as involving "students' induction into the representational conventions and practices of science", and to (ii) "provide a representation rich environment, with opportunities for students to negotiate, integrate, refine, and translate ideas across representations" (Tytler & Prain, 2010, p. 2074). Science learning can then be viewed in terms of attaining fluency in various sets of critical constellations of modes of representation, tools and activities, where each of these modes is seen as having different affordances or "different possibilities for representing disciplinary ways of knowing" (Airey & Linder, 2006, p. 4).

Discourse fluency is defined as "the ability to use a particular mode of disciplinary discourse in a legitimate way" with regard to a certain disciplinary way of knowing (Airey & Linder, 2006, p. 7), seeing both the affordance attributes that are represented and appresented in the constitution of a collective disciplinary affordance (Linder, 2013). Fredlund (2013), however, warns that the achievement of fluency in a set of semiotic resources is not enough to achieve scientific literacy. Students also need to know "which persistent semiotic resources are called for in a given situation" or what their disciplinary affordances are (Fredlund, 2013, p. 69). These semiotic resources afford representational fluency, flexibility, adaptability and competence. Representational fluency is taken as the ability to interpret or construct representations (Ainsworth, Bibby, & Wood, 1998), as well as the ability to translate and switch between representations (on demand) accurately and quickly (Acevedo Nistal, Van Dooren, Clarebout, Elen, & Verschaffel, 2010; Even, 1998).

Students have to become in the words of Kozma and Russell (1997) representationally competent. Kozma and Russell (2005, p. 131) define representational competence as "a set of skills and practices that allow a person reflectively use a variety of representations … singly and together, to think about, communicate and act on … phenomena in terms of underlying, aperceptual physical entities and processes" These skills include the recognition, interpretation, appropriate use of, and construction of content-specific representations (Hilton & Nichols, 2011). Physics lecturers consequently should "understand what each semiotic resource [representation] they use affords (gives to) their students" (Airey et al., 2014, p. 2). They need to appreciate the modes necessary to enable access to all the different parts of the disciplinary knowledge structure needed to achieve the intended learning outcome, including knowledge about the disciplinary affordance of the various modes and how the collective disciplinary affordance of each mode meets the intended learning outcome (Linder, 2013). Lecturers are consequently required to display meta representational competence, meaning "the full range of capabilities … concerning the construction and use of external representations" (diSessa & Sherin, 2000, p. 386). The actions or affordances offered by the use of specific representations during the instruction of a concept or the solving of a problem as part of the act of teaching can be described by the concept 'instructional disciplinary affordances'.

Explicit or strongly directed teaching of representations

Kohl et al. (2007b) distinguish between two approaches when using multiple representations to solve physics problems: explicit or strongly directed teaching (teaching explicit steps and heuristics in solving problems with representations are emphasised throughout the class), and implicit or weakly directed teaching (good use of representations in the solving of problems are modelled by the lecturer, but not explicitly taught). Prain (2009, p. 151) advocate for using an explicit instructional approach arguing that students need to "(i) learn how, why, and when they should interpret and construct models, graphs, tables, and diagrams, and then (ii) integrate these representations with the written language of science". In a study done by Hilton and Nichols (2011), the explicit teaching about the form and function and the relationships between representations contributes to the enhancement of students' conceptual understanding and representational competence. On the other hand, a study done by Treagust, Kuo, Zadnik, Siddiqui, and Won (2012) showed that, even with explicit teaching, a large number of first year non-major physics students could not solve the physics problems effectively. They cautioned that even with explicit teaching, learning physics using different representations is not straightforward. The use of an explicit of direct approach to problem solving is not conclusive.

Active engagement

The importance of actively engaging students to integrate representations has been recognised in literature (Wu & Puntambekar, 2012). As described earlier, affordances are relational properties between students and representations and as such affordances may not be realised without the active engagement of students in the classroom dialogue. The benefit of interactive engagement strategies is reported to be in the increase in the achievement in conceptually difficult courses which is well beyond that obtained by traditional methods (Hake, 2007). Strategies identified to improve engagement of student with representations in a classroom context include designing multiple representation that incorporate interactivity (Wu & Puntambekar, 2012) and having classroom discussions where the features of representations and students' understanding of the various representations become the focus (Kozma & Russell, 1997).

All of the areas alluded to in this chapter will be used to assist attempts to interpret the findings in this study which focuses on introductory physics lecturers reflections on their instructional affordances of representations in physics.

6. CHAPTER SUMMARY

This chapter provides an overview of the theoretical perspectives of reflection and reflective practice in the context of higher education physics teaching linked to a social semiotic affordances perspective on the teaching and learning of representations in introductory physics. This theoretical framework was used to develop an observation protocol for the description of the instructional use of representations by lecturers in their introductory physics classes and produce design-based artefacts to assist with both the stimulation of lecturer reflection on their practice and provide an indication of the level of reflection that they reach. The methodology chosen for answering the research questions, as well as the data generation and analysis strategies followed to solve the questions is described in the next chapter.

CHAPTER THREE

RESEARCH DESIGN AND METHODOLOGY

1. INTRODUCTION

The topics discussed in this chapter focus on the research assumptions and beliefs in which the study is situated (the research paradigm), as well as the tools and processes employed to effectively answers the research questions defined in Chapter one. The first section of the chapter focuses on the theoretical framework that underpins the design-science research design that was used and highlights the implications of this choice in terms of the paradigm, the philosophical assumptions and the ethical considerations of the study. The second section describes and motivates the phases of the research design, introduces the observation protocol and describes how it was constructed, and explains how reflection data were stimulated using the profiles generated and the explanatory key provided.

The basis for the choice of design and methods used is explained in terms of the research questions posed in Chapter one. Interrogation of these questions motivated for the adoption of a design-science approach which aimed at designing and developing an artefact/intervention focusing on the instructional use of representations to initiate and stimulate reflection on the instructional affordances (or constraints) of the representations the participating introductory physics lecturers used during their lectures. The results of the iterative nature of the design which yielded web-based based profiles of the lecturers practice in terms of representational use when teaching physics topics and an online reference manual, is described.

2. PARADIGMATIC STANCE

A paradigm is seen as a set of assumptions and beliefs about "knowledge, our social world, our ability to know that world, and our reasons for knowing it" that frame and guide one's orientation toward research, "including what questions to ask, what methods to use, what knowledge claims to strive for, and what defines high-quality work" (Greene & Caracelli, 1997, pp. 6, 86). "A paradigm is thus a comprehensive belief system, world view, or framework that guides research and practice in a field" (Willis, 2007, p. 8). The term has also come to mean "a set of philosophical assumptions about the phenomena to be studied, about how they can be understood, and even about the proper purpose and product of research" (Hammersley, 2012, p. 2). A particular paradigm "provide[s] researchers with philosophical, theoretical, instrumental and methodological foundations" for the study (Alghamdi & Li, 2013, p. 1). Alghamdi and Li (2013, p. 2) identify the main educational paradigms as "positivism (objectivism and realism); interpretivism (constructivism, naturalism, idealism and rationalism); critical theory (transformativism and relativism) and pragmatism (functionalism)".

Greene (2006) proposes a framework consisting of four interrelated, but conceptually distinct domains that need to be addressed when developing a methodological paradigm for a study (for example qualitative, quantitative or mixed research paradigm). These include: (a) philosophical assumptions and stances (the fundamental philosophical or epistemological assumptions of the methodology, including epistemological, ontological and axiological assumptions), (b) inquiry logics (the research purposes and questions, broad research designs and logic, quality standards, and writing forms traditionally part of the methodological discussion), (c) guidelines for research practice (i.e., specific procedures and tools used to conduct the research planned in the second domain), and (d) socio-political comments (i.e., interests, commitments, and power relations surrounding the location in society in which an inquiry is situated) (see also Greene, 2008). These aspects (except socio-political comments as they were not relevant) were considered when developing the methodological framework for this study.

2.1 Philosophical assumptions

Philosophical assumptions and stances guide a researcher "to look at particular things in particular ways and offers appropriate philosophical and theoretical justification for this way of seeing, observing, and interpreting" (Greene, 2006, p. 93). As such, in order to understand the design used in this study it is necessary to consider the philosophical choices made.

The philosophical stance taken in this study is that it is the research question(s) formulated by the researcher that guides the research process, i.e. it adopts a question-driven approach as outlined by Robertson, McKagan, and Scherr (2013). These authors distinguish between quantitative research, qualitative research, and question-driven research on the basis of the premises and worldviews that frame and guide these particular research orientations, instead of by the data and methods the researcher chooses to use (Robertson, Scherr, & McKagan, 2014).

> *"Quantitative research seeks reproducible, representative patterns and relationships with human behaviour seen as dictated by lawful (albeit*

> *probabilistic) relationships", qualitative research, "seeks to refine and develop theory by linking that theory to cases, while question-driven research prioritizes questions over the pursuit of local meanings or predictable relationships"*
>
> (Robertson et al., 2013, p. 2).

A question driven approach assumes a commitment to the research question(s) of the study in lieu of a commitment to (i) a particular theory of social action/human behaviour or (ii) trust in reproducibility versus multi-layered meaning characterise a question-driven approach to research (Robertson et al., 2014). These commitments mean that researchers privilege research methods that match their specific question at hand, rather than methods that attends to the details of a particular context or those that emphasize representativeness or reproducibility. This movement away from the traditional dichotomy between qualitative and quantitative paradigms to a focus on answering the research question, is supported by Johnson and Onwuegbuzie (2004) who argue for acknowledging the similarities between the various approaches.

> *"Regardless of paradigmatic orientation, all research in the social sciences represents an attempt to provide warranted assertions about human beings (or specific groups of human beings) and the environments in which they live and evolve"*
>
> (Johnson & Onwuegbuzie, 2004, p. 15).

Pragmatists reject 'either or' situations and as such many of the dichotomous arguments present in doing research (qualitative vs. quantitative; subjective vs. objective knowledge; etc.) (Tashakkori & Teddlie, 1998). The above arguments frame the paradigmatic stance of this study, namely that of pragmatic question driven research.

Question-driven research can either be approached from a pragmatic or a dialectic perspective (Robertson et al., 2014). Although both pragmatic and dialectic researchers match question and method, they blend methods for different reasons. Pragmatic researchers blend methods when a single research theme inspires multiple research questions, each of which calls for a different methodology, while dialectic question-driven researchers on the other hand blend methods in order to uncover different facets of the same question, generating insights on the basis of the consistencies and contradictions that emerge (Robertson et al., 2014). In a pragmatic methodology the best suited combination of methods and modes of analysis are applied "that could help provide a credible and valid picture of reality" (du Plessis & Majam, 2010, p. 461). Implicit in this stance is the assumption that different research questions call for different models of social action/human behaviour and, as such, assumptions about the social world and about real phenomena follow *from* a pragmatic choice of research paradigm and method, rather than *directing* these choices (Robertson et al., 2014).

A primary knowledge interest of a pragmatic researcher is trying to translate knowledge into action, taking special interest in the practical consequences this knowledge might have. Goldkuhl (2004) states that an important criterion to use when differentiating between meaningful and not meaningful knowledge is the practicality of the knowledge and concludes that pragmatic research can contribute to practice through a reflective change of perspective which can be understood not only through theory, but via the process of abduction.

2.2 The process of abduction

In light of the question-driven, pragmatic nature of this study, emphasis is placed on the processes of abduction, i.e. “uncovering and relying on the best set of explanations for understanding one’s results” (Onwuegbuzie & Leech, 2006, p. 474). Emphasis is also placed on inter-subjectivity (valuing both objective and subjective knowledge), and transferability instead of the dichotomy of context and generality (Morgan, 2007). The use of abductive logic as a kind of “reasoning that moves back and forth between induction and deduction - first converting observations into theories and then assessing those theories through action” (Morgan, 2007, p. 71). An inductive logic of inquiry (developing the categories captured in the observation protocol based on prior research documented in literature) was employed in this study followed by a deductive approach when the observation findings were used for reflection by the participating lecturers. An inductive approach was then again employed when the lecturers’ reflections were analysed and their level of reflection established.

In the case of this study, the goal was to determine the levels of reflection displayed by the physics lecturers on the instructional affordances their instructional use of representations offered them. This goal is linked to existing theory about affordances and the use of representations in introductory physics classes as a first step in establishing the levels of reflection by the lecturers as a result of a reflective trigger they received. Outcomes of the research are what counts and not necessary prior knowledge claims, laws or even what is true, and trust is primarily to be tested by the practical consequences of belief (Maxcy, 2003).

The final question posed in a pragmatic methodology asks to what extent the findings (or knowledge) of one type of method in one specific setting can be used in other circumstances. Morgan (2007, p. 72) explains that the transferability of research results based on pragmatic research lies more on a "focus on what people can do with the knowledge they produce" rather than "on abstract arguments about the possibility or impossibility of generalizability" which aligns well with design-based research (Alghamdi & Li, 2013, pp. 7-8, citing Instructional Technology Ph.D students at the University of Georgia, 2006; Juuti & Lavonen, 2006). The aim of this study is to design and develop an observation protocol (an artefact) to describe the instructional use of representations by introductory physics lecturers, which in turn can be used to produce another artefact to trigger the lecturers' reflection on the instructional affordances of the representations they used. The emphasis of the study is not only on the artefacts to be designed to gain prescriptive knowledge on the design, but also on descriptive knowledge about reflection by lecturers. As such, the study is embedded in an educational design-based research paradigm. Design-based research "aims both at developing theories about domain-specific learning and the means that are designed to support that learning" (Bakker & Van Eerde, 2014, p. 2).

3. DESIGN-BASED RESEARCH AS AN EMERGING PARADIGM IN EDUCATIONAL RESEARCH

Design is essentially a search process to discover an effective solution to a problem, by the creation of an artefact (Hevner et al., 2004) and has been described as a form of "interventionist research" (Sandoval & Bell, 2004, p. 200) driven by problems of practice and finding a solution of and for practice (Sandoval & Bell, 2004). As such it can be described as a problem solving paradigm concerned with the construction of innovative artefacts (what works) aimed at providing solutions to problems (Hevner et al., 2004). This view of design-based research aligns well with a question-driven research approach where the research problem is central in the research design and process (Barab & Squire, 2004).

A wide range of definitions of design-based research have been presented in the literature (Alghamdi & Li, 2013). In a seminal paper on design-based research in the context of Information Systems, Hevner et al. (2004, p. 77) defined design-based research as "the creation and evaluation of information technology artefacts intended to solve identified organisational problems" that enables the design-based "researchers to understand the problem addressed by the artefact and the feasibility of their approach to its solution". From an educational inquiry perspective, the Design-Based Research Collective (2003) define design-based research as:

> *"... an emerging paradigm for the study of learning [and by implication teaching] in context through the systematic design and study of instructional strategies and tools ... that can help create and extend knowledge about developing, enacting, and sustaining innovative learning environments. ... The intention of design-based research in education is to inquire more broadly into the nature of learning in a complex system and to refine generative or predictive theories of learning"*
>
> (Design-Based Research Collective, 2003, pp. 5, 7).

From a more practical point of view Barab and Squire (2004, p. 2) describe design-based research as "a series of approaches with the intent of producing new theories, artefacts, and practices that account for and potentially impact learning and teaching in naturalistic setting".

The output or result of design-based research is consequently to apply current knowledge of tasks or situations in order to create artefacts that are effective in solving a particular research problem (Hevner et al., 2004). The pivot point around which design-based research balance is evidently the design and development of an artefact embedded in practice that is perceived as problematic. In short a designed artefact can be any designed object with an embedded solution to an understood research problem. Hevner et al. (2004, p. 77) describe the designed artefact as consisting of "constructs [documenting the vocabulary and symbols relevant to the abstract], models (abstractions and representations [linking the problem to the solution]) [used to define the research problems and solutions], methods [techniques or processes used in the solution] and instantiations [an implementation of the construct, model and method in a real-world situation, proving the feasibility of the artefact]". In the context of education, Barab and Squire (2004) identify tangible products such as for example professional development programmes that can be developed and adopted elsewhere with clearly stated outcomes, as examples of artefacts. Plomp (2007, p. 13) refers to interventions that could include "programmes, teaching-learning strategies and materials, products and systems" and other similar types. These interventions, in the words of the Design-Based Research Collective:

> *"... embody specific theoretical claims about teaching and learning, and reflect a commitment to understanding the relationships among theory, designed artefacts, and practice. ... At the same time, research on specific interventions can contribute to theories of learning and teaching"*

(Design-Based Research Collective, 2003, p. 6).

Design-based research as the study's underpinning paradigm draws upon pragmatism. Epistemologically knowledge is seen as contextual and "an interactive process that involves many factors (e.g. personal, mental, and social), and therefore, its formation cannot be studied in isolation" (Abdallah, 2013, p. 933). Knowledge is thus viewed as being collaboratively shaped by researchers and practitioners and, consequently, educational research should be viewed as a collaborative process aiming at simultaneously improving both theory and practice (Abdallah, 2013, p. 934). Design-based research "knowledge claims arise out of actions, situations and consequences rather than antecedent conditions" (Creswell, 2003, p. 11). The value of theory as such lies in its ability to do work, to explain phenomena or to improve practice, and not by their claims to truth (Barab & Squire, 2004). The overarching, explicit concern in design-based research is using methods that link processes of enactment to outcomes, generating knowledge that directly applies to educational practice (Design-Based Research Collective, 2003).

Ontologically, design-based research aligns with a nominalist view, believing that the world cannot be perceived objectively, but is subjectively influenced by social processes (Becker & Niehaves, 2007). Artefacts are designed to contribute to knowledge with the power to provide an organisational benefit or intervention. Secondly, Hevner et al. (2004) require the design-based researcher to communicate the research to audiences at all levels and as such it would be inevitable that this communication would not only influence those individuals to whom the results were directly communicated, but also the society at large.

Different kinds of knowledge are developed in a design study, including practical knowledge of useful and generalisable design practices and theoretical knowledge about better understanding the phenomena addressed by the intervention (Design Based Research Collective, 2003). Accordingly, Edelson (2002, pp. 113-115) identifies three types of theories design-based research can generate, namely: (i) "domain theories (the generalisation of some portion of a problem analysis contributing to either context theories or outcomes theories); (ii) design frameworks (a generalised design solution describing the characteristics that a designed artefact must have to achieve a particular set of goals in a particular context); and (iii) design methodologies (a general design procedure providing guidelines for the process rather than the product)".

In summary, the common features of design-based research is that it is research that produces "theories on learning and teaching; are interventionist (involving some sort of design); take place in naturalistic contexts; and are iterative" (Barab & Squire, 2004, pp. 2-3). Design-based research thus produces both useful products (e.g., educational materials) and accompanying scientific insights into how these products can be used in education (Van den Akker, Gravemeijer, McKenney, & Nieveen, 2006). A suitable methodology that would provide an opportunity with the best chance to rigorously execute design-based research should thus incorporate these features.

3.1 Design-Based methodology

The methodology of research conducted in a particular research paradigm constitutes the general guidelines, tasks, and processes necessary for the successful completion of a research project. The guidelines for conducting design-based research suggest that it should be conducted as a search process that use available resources to construct an intended artefact that would solve the identified research problem, followed by a rigorous evaluation of the "artefact's utility, quality and efficiency" (Hevner et al., 2004, p. 85). These authors' formulated seven guidelines to assist the design-based researcher to contribute to the body of design knowledge in a rigorous manner (see summary in Table 3.1).

Hevner and colleagues, however, caution against the mandatory or rote use of the guidelines inviting researchers to use their judgement to determine when, where and how to apply each of the guidelines in a specific project (Hevner et al., 2004). Although the guidelines in Table 3.1 were formulated in the context of Information Systems Research, the general theoretical assumptions behind them are applicable in the context of this study and will be re-visited in the final chapter in order to establish the extent to which it succeeded in conducting design-based research effectively.

Table 3.1: Design-based research guidelines (table quoted from Hevner et al., 2004, p. 83)

Guideline	Description
1: Design as an Artefact	Design-science research must produce a viable artefact in the form of a construct, a method, or an instantiation.
2: Problem relevance	The objective of design-science research is to develop technology-based solutions to important and relevant business problems.
3: Design Evaluation	The utility, quality, and efficacy of a design artefact must be rigorously demonstrated via well-executed evaluation methods.
4: Research Contributions	Effective design-based research must provide clear and verifiable contributions in the areas of the design artefact, design

Guideline	Description
	foundations, and/or design methodologies.
5: Research Rigour	Design-science research relies upon the application of rigorous methods in both the construction and evaluation of the design artefact.
6: Design as a Search Process	The search for an effective artefact requires utilising available means to reach desired ends while satisfying laws in the problem environment.
7: Communication of Research	Design-science research must be presented effectively both to technology-oriented as well as management-oriented audiences.

Writers of methodological literature suggest the use of cycles in the design research process. Hevner (2007) identifies three research cycles inherent in design-based research, namely: the relevance cycle, the rigour cycle and the design cycle. The relationship between these three cycles is illustrated in Figure 3.1 (adapted from Hevner, 2007).

> *"The Relevance Cycle bridges the contextual environment of the research project with the design science activities. The Rigour Cycle connects the design science activities with the knowledge base of scientific foundations, experience, and expertise that informs the research project. The central Design Cycle iterates between the core activities of building and evaluating the design artefacts and processes of the research"*
>
> (Hevner, 2007, p. 2).

Hevner (2007) explains that the three cycles are dependent on each other. The relevance cycle is concerned with the context of the research as well as with the identification of the acceptance criteria for the designed artefact. It initiates the research and feeds knowledge into the design cycle to ensure relevance of the artefact designed. The rigour cycle focuses on the existing knowledge base ensuring a solid theoretical grounding, as well as ensuring the designed artefact indeed represent new additions to the knowledge base. The design and evaluation theories and methods used during the field testing of the designed artefact are drawn from the rigour cycle. In the words of Hevner (2007, p. 5): “It is the synergy between relevance and rigor and the contributions along both the relevance cycle and the rigor cycle that define good [design-based] research”.

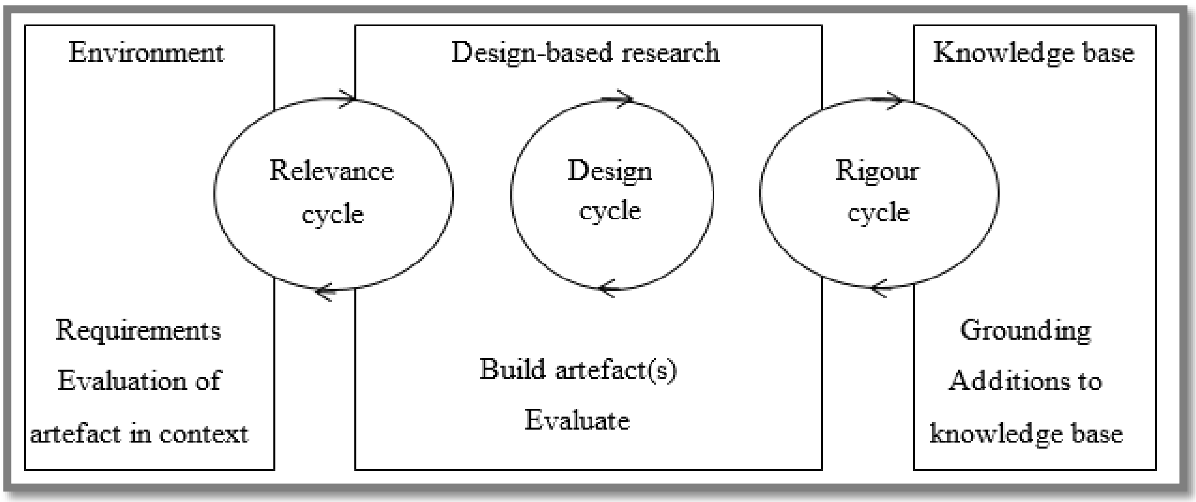


Figure 3.1: The three design cycles inherent in a design-based research project (adapted from Hevner, 2007)

In addition to the cyclic nature of conducting design-based research, Peffers, Tuunanen, Rothenberger, and Chatterjee (2008, pp. 55-56) argue for a design-based research methodology that consists of six activities, namely (i) Problem identification and motivation during which the specific research problem is defined with a justification for the value of a solution; (ii) Define the objectives for a solution based on the problem definition; (iii) Design and development the artefact (any designed object in which a research contribution is embedded in the design); (iv) Demonstration of the artefact (This could involve the use of the artefact(s) as part of a case study.); (v) Evaluation of how well the artefact supports a solution to the problem by comparing the objectives of a solution to actual observed results from use of the artefact in the demonstration; and (vi) Communication of the problem, its importance, the artefact, its utility and novelty, the rigour of the design, and its effectiveness to researchers and other relevant audiences. The actual design utilised in this study loosely incorporated both the cyclic nature of conducting design-based research and the research activities as identified by Peffers et al. (2008) resulting in the three-phase design explained in the next section.

3.2 Justification for use of design-based methodology

There are a number of reasons why a design-based approach is appropriate for this research study. Firstly, design-based research methods are of particular importance for interdisciplinary studies at a time when social science is increasingly ‘post-disciplinary’ both in conceptualisation and in practical application (Design-Based Research Collective, 2003). This study, which crosses the disciplines of physics education and professional development of higher education lecturers, is an example of the type of interdisciplinarity well matched for a design-based approach. Secondly, design-based methods are a central part of the repertoire of applied social research such as education (Design-Based Research Collective, 2003). Applied research aims at providing knowledge that can be used to solve practical problems (Swanborn, 2010), as is the case of investigating whether the use of a reflection trigger such as the profiles produced in this study result in reflection by the lecturers on the affordances offered by their instructional use of representations.

Thirdly, contextuality is provided by the fact that the intention is for the physics lectures to be enabled and assisted to reflect on their own practice, something which is central to design-based research (Design-Based Research Collective, 2003; Hoadley, 2004). The intervention or artefact as enacted is seen as at least an outcome of the study (Design-Based Research Collective, 2003).

> *"Design-based research views a successful innovation as a joint product of designed intervention and the context. ... The value of attending to context is not simply that it produces a better understanding of an intervention, but also that it can lead to improved theoretical accounts of teaching and learning"*
>
> (Design-Based Research Collective, 2003, p. 7)

4. RESEARCH DESIGN

What follows in this section is a discussion of the study's design or "the argument for the logical steps which will be taken to link the research questions and issues to data collection, analysis and interpretation in a coherent way" (Hartley, 2004, p. 326). As stated in the introduction, the purpose of this study is the development of an observation protocol, as well as instrument fidelity (the procedures used to maximise the utility and/or appropriateness of the instruments used in the study) (Hahs-Vaughn & Onwuegbuzie, 2010), and as such a three phase design was chosen to achieve this purpose.

4.1 Design phases

Drawing on the principles of design-based research alluded to in the previous section, as well as the suggestions offered on how to conduct rigorous design-based research, this study is divided into three phases focusing on the development of an artefact to support introductory physics lecturers reflect on their instructional practice. The division of the study into three phases was intended for organisational purposes. In reality the phases were connected. During each of the research phases, a number of research activities were undertaken to ensure the successful completion of the study. Figure 3.2 illustrates the mapping of these research activities onto the research activities proposed by Peffers et al. (2008). Successful completion of the study relies on iteratively cycling between the activities in the phases, in order to incorporate new insights and ensure that the artefact address the domain of the study effectively. Throughout phases two and three the instruments and techniques used for data collection were developed in the light of the needs of the research and the specific purposes of the study.

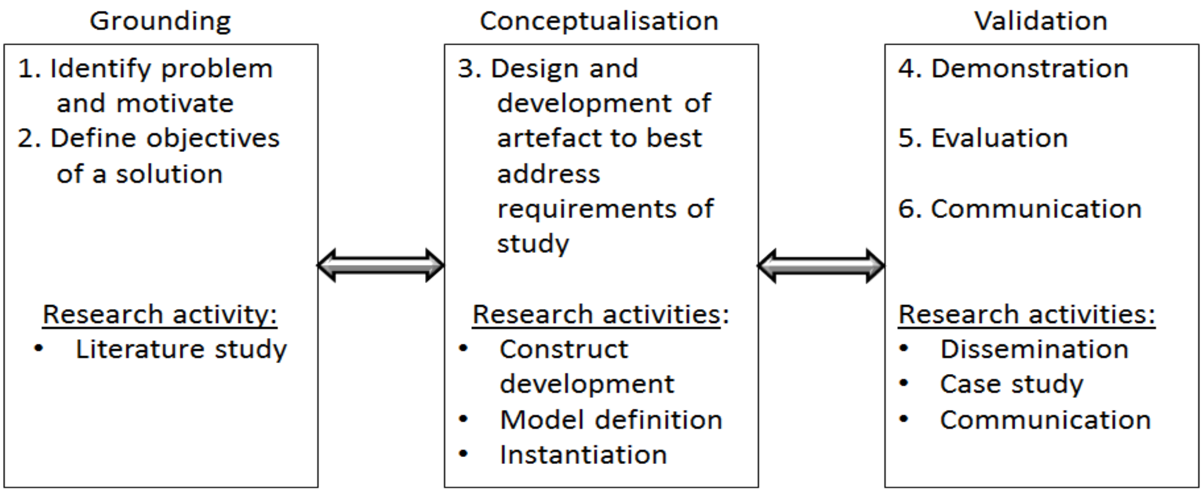


Figure 3.2: The three phase research design with the associated research activities adopted for this study

Phase One: Grounding

The purpose of the first phase of the study is to investigate the problem domain to get a better understanding of the problem. This phase involves the identification and formulation of the research problem, which allows for objectives to be formulated for the artefact to address the problem formulated. The identification, contextualisation and formulation of the research problem have taken place in chapter one. The artefact proposed as solution to the identified problem identified in chapter one consists of three individual artefacts (a construct, a model and an instantiation) to assist the introductory physics lecturers to bridge the gap between physics education research and their instructional and reflective practices. The artefact is grounded in existing knowledge on the instructional use of representations in physics and reflective practice in the context of higher education through an extensive review of the existing knowledge base related to these domains (see Chapter two). The grounding of the artefact in literature attempts to enable it to provide a contribution to the existing knowledge base. The insights gained from the review of the literature are used to determine the criteria for the evaluation of the artefact as implemented in the third research phase.

Phase Two: Conceptualisation

In this phase the domain knowledge from the first phase is used to design an artefact to address the requirements of the study as identified in Chapter one. The solution proposed to address the research problem identified in phase one entail an observation protocol (the model representing the design problem and its solution in a real-world context), together with an explanatory key (the construct providing the language in which the research problem and solutions are defined and communicated) and instantiation (proof-of-concept) that could be used to address the research problem identified for this study. The protocol is grounded in theory about the instructional use of representations in introductory physics classes. The design of the prototype protocol and explanatory key went through iterative cycles of refinement to ensure that the artefacts have relevance to the stakeholders in the research project, as required by Hevner (2007). These iterations added rigour to the artefacts and are discussed in more detail in chapter four.

Phase Three: Validation

The final phase, namely Validation, consists of finding suitable platforms for the dissemination, demonstration and communication of the results of the conceptualisation phase. The results of the study and how the artefacts may be applied to the problem domain were communicated to the participating lecturers. This phase establish whether the designed artefact (the web-based resource in conjunction with the observation protocol and explanatory key) meets the pre-determined specifications and in the process address the identified research problem. The relevance of the developed artefact in providing a useful solution, as well as ensuring the artefact contributes to the greater scientific knowledge base is ensured (Hevner et al., 2004).

The feasibility of the web-based resource to stimulate and enhance reflection by introductory physics lecturers was evaluated using video-stimulated recall interviews with the individual participating lecturers. Feedback gained from the interviews was used to iterate back through phase one and two. The formative evaluation of the artefact is aimed at improving and refining the materials, approach and theory. The findings of the validation phase informed further recommendations for solving the research problem (Plomp, 2007). Lastly the designed artefact will be communicated to the physics community at large in the form of this report and envisaged conference presentations and journal articles.

The sections and subsections to follow address the various research activities related to the three phases of the design-based methodology adopted for this study. Each activity is discussed individually for organisational purposes.

5. RESEARCH ACTIVITY – GROUNDING

This section provides a brief overview of the research activity related to the grounding phase of the research design. The grounding is based in the literature review in chapter two which focused on two domains of knowledge. The first knowledge based consulted focused on reflection in the context of higher education teaching and the reflective practice of physics lecturers in particular. The second knowledge based consulted entailed Physics Education Research related to the importance of representations in physics and the use of representations as part of teaching in a higher education context. The focus on multiple representations in constructing knowledge has been identified as an area of research that will contribute to "a broader and productive scholarship and deeper and enriched understanding of both teaching and learning" (Yore & Treagust, 2006, p. 291). This phase developed the theoretical framework that informed the design of the artefact proposed as solution to the research problem identified for this study.

6. RESEARCH ACTIVITIES - CONCEPTUALISATION

This section addresses the various activities related to the conceptualisation phase of the research design. The methods employed to generate the required data and the issues associated with the use of such methods are considered below.

6.1 Construct development

The first research activity in the design cycle (namely grounding) involved the development of the construct for the proposed artefact. As constructs "… provide the vocabulary and symbols used to define problems and solutions" (Hevner et al., 2004, p. 83) they have a significant impact on how tasks and problems are conceived. Hevner et al. (2004, p. 83) also note that constructs "… enable the construction of models or representations of the problem domain" (the instructional use of representations in introductory physics) - a crucial aspect of finding an effective design solution. The terminology identified of relevance to the domain of the instructional use of representations in physics were captured in the explanatory key, which was developed to accompany the observational protocol for the Instructional use of Representations in Physics (see Appendix B for the Reference Manual containing both the explanatory key and observation protocol).

6.2 Development of observation protocol

A model is an abstraction which makes a phenomenon clearer, while highlighting the most important factors and how they interact (Hammond & Wellington, 2012, p. 171). The envisaged observation protocol is an abstraction of the current knowledge based on the problem domain, making the complex knowledge base clearer, while highlighting the important factors of particular relevance in the context of observing manifested practices in introductory physics classes. A careful examination of the observation protocols available in related literature revealed that none of the available observational protocols fully met the needs of this study. The observation protocol was developed based on literature around the instructional use of representations in physics classes to guide the selection of video segments for further analysis (see Appendix B). A purpose specific observation protocol was developed following Bryman's (2012) guidelines, complemented by the standard procedure for developing a valid and reliable measuring instrument as documented by Akbari, Behzadpoor, and Dadvand (2010). The aspects taken into account during the development of the observation protocol included: (a) a clear focus; (b) the forms taken by any category of behaviour must be mutually exclusive (not overlapping) and inclusive; (iii) the recording system must be easy to operate; and (iv) in the event of interpretation needed by the observer, an explanatory key is needed (Bryman, 2012). The refinement of the observation protocol based on the feedback received during the instantiation of the protocol is discussed in Chapter four.

6.3 Instantiation

An instantiation of the protocol and the accompanying explanatory key constitute the third research activity in this phase. The instantiation of the protocol and the explanatory key illustrate the implementation of the construct and model in a real-life working context, demonstrating their feasibility, and the artefact's suitability to its intended purpose (Hevner et al., 2004). The third aspect of the artefact is thus the product of applying the observation protocol supported by and the explanatory key to video data generated by observing the classroom practice of the participating lecturers, namely a set of profiles generated of the instructional use of representations by the participating lecturers (see the Compact Disc [CD] supplied with this manuscript for all five web-based resources for the five lecturers and to see the video links). Two iterations of this abstract were undertaken producing firstly a set of paper-based profiles and on the second instantiation a web-based resource containing the various profiles representing the outcome of the designed artefact.

Case study

A case study approach was used to implement the protocol. There are some differences in how researchers define case studies. Some think of it as a process of investigation (Creswell, 2002); an in-depth exploration of a bounded system based on extensive data collection. Yin (2012) is of the view that case study research can be used to evaluate the outcomes of interventions. Yin states that:

> *" ... a case study is an empirical inquiry that investigates a contemporary phenomenon within its real life context, especially when the boundaries between phenomenon and context are not clearly evident"*
>
> (Yin, 2014, p. 16).

In Yin's conceptualisation, the phenomenon can be more tangible such as individuals and organisations, and it can also be less tangible such as relationships and processes. This conceptualisation suits the purpose of this phase of the study where the focus is on the implementation of the designed artefacts in the real-life context of the intended users of the artefacts.

Context of the study

Context is important for the instantiation both from a case study perspective and from the design-research perspective. The designed artefact should not be independent of the social context in which it will be used (Hevner et al., 2004) and as such the positioning of the research in naturalistic contexts forms a core part of an applied study framed as a design-based research (Barab & Squire, 2004). The context of the study is introductory physics and the representational practice of introductory physics lecturers. As the goal of this research is to gain insights into an event (the instructional use of representations by introductory physics lecturers), it resulted in the purposeful selection of introductory physics as the context for the study and a selection of the individual lecturers based on convenience (Onwuegbuzie & Collins, 2007). The introductory physics context was purposively selected as representations are important in the teaching and learning of physics, and more specifically in the introductory modules, as much of the focus of instruction in introductory physics courses is developing competency in external representations to provide tools for the development of internal models and representations. As such, this study focuses on introductory physics lecturers' instructional use of representations and their reflections on the instructional affordances of their representational use.

Selection of participants

Introductory physics is offered to a variety of students who are registered in diverse faculties across the university, including both diploma and degrees offered in the Faculties of Science, Engineering, Built Environment and Information Technology, Health Sciences and Education. Seven lecturers in the Physics Department and one lecturer in the Department of Mechanical Engineering who are involved in introductory (first year) physics courses at the university were invited to participate in the study. Five lecturers in total from the Departments of Physics (n=4) and Mechanical Engineering (n=1) took up the invitation to participate in the study.

Generating video data from systematic classroom observations

Considering the gap recorded between stated and actual behaviour experienced when using data collection strategies such as self-completed questionnaires or interviews, systematic classroom observation was chosen as method of data collection in preference to interviews (Bryman, 2012) to determine the instructional use of representations by the participating lecturers. Systematic classroom observations avoid reliance on memory or perception when investigating classroom practices and it uses explicitly formulated rules (or a coding system) for the observation and recording of behaviour in its natural environment (Bryman, 2012). Each participant's instructional practice was systematically observed and recorded for a predetermined period of time using the same rules (usually referred to as an observation schedule). To increase the internal reliability of the study video recordings of the classroom observation were made. See section 8.2 for a further discussion on the internal reliability of the study. Based on the various decisions that were taken during the filming of the classroom practice (such as for example where the camera will be focused, what were included in the video recordings and what was excluded, etc.), it can be argued that the video-recordings were data constructed by the researcher (Hall, 2000) and not merely collected data. Informed consent for the recording of the video data was received from each of the participating lecturers (see Appendix A).

Sampling during video data generation

The actual observations happened in the second semester of the academic year and the lecturers were asked to supply the researcher with date and times of their classes. Suitable classes to be observed were negotiated with the lecturers, depending on availability of the researcher and the lecturers. Observations were scheduled up to a week in advance with the stated purpose of observing the use of representations by lecturers during their instruction. The observations were not scheduled close to examination time or just before a test had to be written since these events might have influenced the instructional strategies of the lecturer involved (Bryman, 2012).

The decision on how many lessons of each lecturer would be observed was based on a sampling strategy known as 'subgroup sampling' with a recommendation of three or more participants per subgroup for exploratory studies, or in the context of this study, three 90 min classes per lecturer (Onwuegbuzie & Collins, 2007; Onwuegbuzie & Leech, 2007). Having three consecutive lessons for each of the five participants observed and recorded allowed the observations to be conducted "systematically and repeatedly over varying conditions," that is, recording the lessons at different times and places in order to "ensure the widest range of observational consistency" (Adler & Adler, 1994, p. 381). It also resulted in allowing the researcher to experience sustained contact with the classroom events in their natural setting (Baker, 2006). A "comfortable degree of rapport, even intimacy, [was established] with the people, situation, and settings of research" (Jorgensen, 1989, p. 21). The chosen time spent in the classes allowed the students and the lecturers to get used to my presence in their classes while they were engaged in their everyday cultural or social relationships – attending or teaching their class (Franklin, 2012) and as such contributed to the credibility of the observational data.

The last sampling decision to consider involves deciding on the focus of the planned classroom observation; a technique called focal sampling (Bryman, 2012). During the classroom observations the focus of the observation was on the instructional use of representations by the lecturers during the time allocated as a lesson scheduled on the students' time-table. The video camera was zoomed in on the actions of the lecturer, including any instructional resources (e.g. the white board or the overhead projector) they may have used during the class. This excluded as far as possible any recordings of student activities. The observations did not include any instruction that happened outside the time-frame as indicated. The observation was further focused through the use of the developed observation protocol. The above stated sampling strategies contributed to the interpretive consistency of the study; an indication of the consistency between the inferences made by the researcher and the sampling design chosen for the study (Collins, Onwuegbuzie, & Jiao, 2006).

The role that I took in the classrooms was that of a passive observer. At no time did I intervene during the lesson or engage with the students or the lecturer, except at the beginning of the first observation sessions when I was introduced to the students and my involvement in their classes explained. The lecturers' classroom practice was recorded by positioning a digital video camera (operated by the researcher) at the back of the class to minimise the impact of the presence of the video camera on the natural flow of the lesson. At the same time I acknowledge that my presence within the classrooms might have influenced the lectures actions during the observations. Video recordings are not immune to the effect of researchers' subjectivities.

Challenges of generating video data

Video recording of classroom observation poses some methodological challenges (Derry et al., 2010; Rosenstein, 2002). The large amount of data generated by video-taping of instructional practice creates challenges for analysis (Derry et al., 2010). Derry and her colleagues recommend that researchers use the research questions and a theoretical framework as a way to focus on the extraction of data and meaning from the large amount of video data available. Another potential threat to the validity of classroom observation is "researcher bias that may result from selective observation, selective recording of information, or the subjective interpretation of situations" (Baker, 2006), which can lead to selective perception (White & Marsh, 2006).

Because of the various levels of selection involved in the generation of video data from the classroom observation, and the influence of theoretical frameworks (and research questions) on these selection choices, video-recordings classroom practices cannot be taken as objective and theory neutral data (Hall, 2000). Some researchers see the concern of whether the video data captured reality and whether the generation of video data "adulterates and distorts events beyond usefulness" as a threat to the validity and reliability of video data (Jewitt, 2012, p. 10). Jewitt argues that the "desire to capture and preserve reality", which has an underlying focus on reality and objectivity, is rejected by some researchers who only see video data as a tool for reflection. The stance in this study is taken that the value in the video data generated lies in its ability to "preserve the [classroom] interaction for re-presentation and participants' awareness of that ability" (Jewitt, 2012, p. 10). The video recording of the lecturers' instructional use of representations in their physics classrooms was chosen with this perspective in mind. This approach renders the debate around the validity (did it capture what is really going on) and reliability (was the natural environment distorted by the presence of the camera) of the data irrelevant since the influence of the video recording on the lecturers' practice become a point of reflection (Jewitt, 2012).

Analysis of video data

"All analysis involves a movement from raw data to refined conclusions, a process that is a form of reduction" (Collier & Collier, 1986, p. 169). As such a deductive approach was used where the coding categories contained in the observation protocol, accompanied with the operational definitions of the categories, were used as analytical framework to sift the video data (Hsieh & Shannon, 2005; Kondracki, Wellman, & Amundson, 2002). Mayring's structural content analysis strategy was used as overall analytical strategy to analyse the video-recorded observational data. Content analysis is "a data analysis technique for making replicable and valid inferences from texts (or other meaningful matter) to the contexts of their use" (Krippendorff, 1989, p. 18). It applies a systematic, theory-guided approach to text analysis using a category system (Mayring, 2000), and as such allows the researcher to make replicable and valid inferences from texts (Krippendorff, 1989, p. 18).

The focus of the analysis was on the manifest content of the instructional practice, or the content that is visible at the surface level of the text in contrast with the latent meaning of the data (Berg, 2001), as captured in the observation protocol developed for this study. This allowed the analysis to move from the enacted behaviour captured in the videos of lecturers' classroom practice to providing answers to the research questions (Krippendorff, 2004, p. 173). Due to the density of the medium, sampling within the data was done to focus only on the events that involved the use of representations in the instruction (Collier & Collier, 1986).

The next step involved the coding of the raw data. This step is the heart and soul of content analysis with its key tool being the system of categorisations (Ryan & Bernard, 2003). The video, rather than transcripts of the video recordings, was consequently used as the data source (DeCuir-Gunby, Marshall, & McCulloch, 2012). Instead of adding to the amount of data by creating lengthy and time-consuming transcriptions of the verbalisation or verbal responses captured on the video recordings, Pirie (1996) advises not to transcribe the recordings, but to work directly from the video tapes. Added to the above reason, is the fact that the aim of the data analysis was to document the different representations used by the lecturers and not how many times they used a particular representation. A single comment or observation of a particular representation used during instruction was considered important and coded applying the observation protocol (Fereday & Muir-Cochrane, 2006). This approach was taken and the coding process was essentially one of organising the content in a manner that allows for easy identification, indexing, or retrieval of content relevant to research questions and captured in the observation protocol developed in the first phase of the study (Merriam, 1998). As such this activity requires analytic thinking (Marshall & Rossman, 2011). The coding allowed for identification of emerging categories and themes, helping the researcher to see connections between data (Goodnough, 2011).

The level of analysis was conceptual analysis – the reoccurrence of concepts related to the instructional use of representations such as the nature of the representations used, the educational environment during the instruction, the functions of the representations, etc. The video was coded at the level of instructional events (the smallest distinguishing meaningful idea namely the instructional use of a representation as represented on the observation protocol) that manifested in the visual data. It was clear from the outset that the protocol items, used reliably across observers to mean the same thing, would not produce a meaningful single rating or score. Instead it appeared evident that the best use of the instrument would be to produce a graphical profile of instruction i.e. a qualitative description of the instructional environment under investigation.

The results of the instantiation of the observation protocol in the context of video data generated from systematic classroom observations are discussed in Chapter four. The section and sub-sections to follow focus on the methods employed to successfully accomplish the last of the design-based research cycles, namely the validation phase.

7. RESEARCH ACTIVITIES – VALIDATION

This section addresses the various research activities related to the validation phase of the study. The two main research activities performed in this phase entail the demonstration and communication of the artefact to the participant lecturers, followed by an evaluation of the artefact by the lecturers in terms of its applicability and feasibility to the context for which the artefact was developed.

7.1 Demonstration

The set of profiles of the lecturers' individual and combined instructional use of representations resulting from the analysis of the observational data, as well as short video snippets of events captured by the video data from the classroom observations serving as evidence of the manifested instructional practice, were packaged in the form of a web-based resource for the lecturers' use. The link to this artefact was send to the lecturers in an e-mail inviting them to an interview with the aim to assess the feasibility of the artefact to trigger or enhance their reflections on the instructional affordance of their representational use during their physics instruction. By sending the link to the participating lecturers prior to the interview, and the demonstration of the artefact to the lecturers, they were allowed time to reflect and revisit the resources (Reitano, 2005) at their convenience and in a safe, non-threatening environment (Calderhead, 1981; Reitano, 2005). The artefact was further demonstrated by the researcher during the individual interviews (see next research activity).

7.2 Evaluation

Individual face-to-face interviews were used to elicit feedback from the five participants on the utility of the artefact designed. The aim of the interviews was to engage the participants in an evaluation of the artefact representing their instructional practice in order to determine the usability of the artefact to stimulate and enhance their reflective practice. An interview protocol was developed for the evaluation (see Appendix C). The interview questions were organised around three themes, namely validation of the research outcome (the profiles of each individual lecturer captured in the web-based resource), a summative evaluation of the instantiation of the designed artefact (the web-based resource) and lastly a video stimulated reflection section to establish the level of reflection displayed by the participating lecturers after they have experienced the instantiation of the designed artefacts.

7.3 Reflection by lecturers

Part of the validation phase of the design-research project is to establish the level of reflection the participating lecturers display in terms of the instructional affordances of their particular use of representations in their introductory physics classes when they are provided with a personal profile of their instructional practice and an explanatory key acting as reflective triggers. Videos stimulated reflection interviews were conducted to engage the lecturers in a discussion around the instructional affordances offered by the representations the participating lecturers used in their instruction, based on evidence from the actual observation of their classroom and not just a recall of their practice.

The video stimulated reflection interview allows a researcher to elicit the lecturers' thoughts and knowledge used during instruction (Reitano, 2005) and is an effective technique for investigating the cognitive processes used during instruction by asking the participants to recall (when prompted by a video segment) their thinking and decisions during that event, as well as the reasons for acting as they do (Lyle, 2003; Otero & Harlow, 2009; Reitano, 2005, p. 383; Smith & Neale, 1989). The value using the video recording of the instructional practice as stimulus for reflection lies in its ability to preserve some aspects of the practice for "re-presentation" (Jewitt, 2012). Combining semi-structured interviews with video-stimulated reflection gave the researcher the best of both worlds; authentic reflection on the instruction practices of the lecturers, as well as a discussion instead or just a description of these practices.

A video stimulated reflection interview is the least disruptive, but also most objective, technique to elicit reflections from the lecturers on their instructional use of representations and the affordances the representations used during instruction offered the lecturers (Pirie, 1996). Lecturers are enabled to distance themselves from the immediacy of their instructional practice and observe themselves, shifting their professional vision to areas that might not be noticed while teaching (Jaworski, 1994); they gain powerful insights into what it is like to be in their classrooms (Tochon, 2007; Van Es & Sherin, 2010); and they can watch the videos more than once, allowing patterns to be recognised that may have been missed during an observation, opening the possibility for a richer representation of an event (Otero & Harlow, 2009; Van Es & Sherin, 2010).

A standard semi-structured interview protocol was developed (see Appendix C). The participants were asked to reflect on the instructional affordance the representations they used in their instruction afforded their students (their thinking and tacit knowledge on teaching with representations). The technique of video stimulated reflection was incorporated in the interview by providing the lecturers with their individual profiles generated during the first phase of the study, supplemented with video segments of their instructional practice to serve as stimulation for their reflection.

Following Reitano's (2005) lead, each lecturer was provided with a personalised profile of his or her instructional use of representations as represented by the sample of observational data of their classroom practice, a key on how to interpret the profile, as well as an interview schedule focusing on the possible application and benefit of such a profile to the lecturers' teaching practice prior to the interview to watch. This provided the participants with ample time to reflect on the questions and their teaching practice. Individual semi-structured interviews were conducted in a safe environment with each lecturer (their offices).

It must however be mentioned that, unlike data of reflections captured in reflective journals, for example, the data collected by using the VSR interviews do not represent the development of the participants' reflective practice over time. It is rather a snap-shot of their reflection at a particular point in time.

Data analysis

A hybrid approach of inductive and deductive coding and theme development (Fereday & Muir-Cochrane, 2006) was used, incorporating both the deductive a priori template of codes approach developed by Crabtree and Miller (1999), and the data driven inductive approach of Boyatzis (1998). The analytic process used to analyse the data followed the procedure as described by Braun and Clarke (2006). The first step in the analytic process included the transcription of each of the five interviews conducted with the participating lecturers (see Appendix C for an extract on an interview). The second step was followed by an intimate familiarisation with the data.

Coding is a mechanism for thinking about the meaning of data and reducing the vast amount of data generated during the interviews (Huberman & Miles, 1994) and in the process moving from managing and organising the data to interpreting and theorizing about the data. It means generating an index of terms that will help the researcher with interpretation and theorising in relation to the data (Bryman, 2012). The transcribed interview data was organised into the three sections as explained earlier (validation data, data relevant to the evaluation of the artefact and reflection data) to facilitate the coding and identification of themes from the data.

The coding process for the first two sections was inductive and started with the generation of an initial list of interesting ideas forming initial codes which refer to either validating the profiles generated or statements related to the evaluation of the designed artefacts (Boyatzis, 1998). After the first round of coding, it is necessary to review the codes by reducing overlap, considering more general theoretical ideas in relation to codes and data (Bryman, 2012).

For the deductive approach used to analyse the data relevant to the level of reflection achieved by the lecturers, I interpreted Ward and McCotter's (2004, p. 248) definition of reflection as "any text focusing on a specific teaching action" in the context of the interviews as any statement made by the lecturers focusing on a specific teaching action as representing reflection on the instructional affordance of their instructional practice. It is assumed that statements made during the interview were deliberately chosen by the participants to be part of their reflection on the actions and possibilities (as well as the constraints) of their instructional practice.

I read and re-read the data to identify statements that could be coded as reflection (as defined above). These codes were re-read again to assign the relevant code for the level of reflection displayed (keeping in mind the purpose of the study namely establishing the level of reflection evident after the video stimulated reflection interviews). The levels of reflection categories were assigned using a Level of Reflective Practice taxonomy developed as part of the review of the literature (see Chapter two, section 3.8). The taxonomy was developed using the SOLO taxonomy as basis. The assessment of the level(s) of reflection by the lecturers happened at a whole interview level and not at a section within the paper, level. The interview was a whole was examined to find the highest level of reflection (Kember et al., 2008). The codes used were in increasing order: reporting, responding, relating, reasoning and reconstructing (see Chapter two, section 3.8).

8. RIGOUR IN DESIGN-BASED RESEARCH

The positioning of the study in a pragmatic paradigm with a question driven research approach plus the argument by Hoadley (2004, p. 204) that "the notion of [methodological] alignment is essential to your understanding of research validity" influenced understandings of rigour in this study. This alignment viewpoint is supported by Robertson et al. (2014), as well as Pratt (2008), who argue that research conducted by question-driven physics education researchers should be evaluated on the basis of the clarity with which the researcher ties together his methods, assumptions, findings and research questions. The stance thus taken in this study is that quality in any research project depends on two areas in the research process: (1) the quality of the design focusing on the degree to which a researcher has selected the most appropriate procedures for answering the research questions in the words of Teddlie and Tashakkori (2009); and (2) the quality of the explanations provided focusing on the degree to which credible interpretations have been made on the basis of obtained results (Tashakkori & Teddlie, 2003). These aspects of quality were collated into the 'Integrative Framework for Mixed Methods Inference Quality' formulated by Venkatesh, Brown, and Bala (2013). Although the framework was originally formulated in the context of mixed methods research, this case study shares the underlying paradigm of pragmatism with that of mixed-methods research and as such the broad ideas of the framework were used as framework to report on the quality of this study.

The three indicators of a quality design, namely design suitability or appropriateness, design adequacy and analytic adequacy (Venkatesh et al., 2013), are mostly dealt with under each of the research design components. The second quality inference criterion, namely explanation quality, will be evident within the chapters to follow where the results of the analytic process are presented, discussed and reflected upon. Using the argument presented by Cohen, Manion, Morrison, and Morrison (2007) that qualitative data can be treated like quantitative data when considering the stability of observations, and the argument by Barab and Squire (2004, p. 8) that "trustworthiness and credibility are akin to reliability and validity but not necessarily require the use of objective and quantitative methods for demonstrating they have been met", rigour in the design of the research will be communicated in the sections and sub-sections to follow.

8.1 Validity strategies employed

As mentioned earlier ,"[t]he notion of alignment is essential in our understanding of research validity" (Hoadley, 2004). Validity in research requires alignment among observations (or data), measurement instruments (coding schemes, in this case), and theoretical paradigms (Kirk & Miller, 1986) and is of concern whenever sampling decisions have been made (Kondracki et al., 2002).

A variety of validity procedures were incorporated in the design of this study including striving to "establish a clear chain of evidence in order to allow the reader to reconstruct how the researcher went from the initial research questions to the final conclusions" (Yin, 2003, p. 102). In his article on methodological alignment in design-based research, Hoadley (2004), argued for the importance of three types of validity in this type of research: treatment validity (ensuring the treatments we create accurately align with the theories they are representing), systemic validity (not only design research that is a fair test of the theories, but communicating the theories in such a way that it is true to the inferences use to prove them) and consequential validity (considering how the interpreted results of the research will be applied in practice to future prediction and implementation).

In terms of ensuring the quality of the research design, elements of triangulation were implemented to ensure rigour (Creswell, 2003). The process of triangulation was used to seek common ground in the data and to confirm or disconfirm emerging categories and themes (Creswell & Miller, 2000). Methodological triangulation (Creswell & Miller, 2000) was employed by using multiple sources (five participants) and types of data (observations and interviews,) complemented by collecting data from multiple sources (Creswell & Miller, 2000; Merriam, 1998). Triangulation was further enhanced by implementing strategies to increase internal validity of the study. Yin (2012) identified a clear theoretical framework explicitly derived from the literature that is driving the analysis of the data, which, combined with the process of pattern-matching where the empirically derived patterns identified are compared with patterns established in literature and different contexts (Eisenhardt, 1989), is essential to achieve theoretical triangulation. The theoretical framework (social semiotic affordance theory linked to reflective practice) discussed at length in chapter two, formed the framework that guided the analysis of the case study data.

Criterion validity, which refers to the accuracy of findings, was addressed by using field notes and video recordings of the classroom actions of the lecturers. The data were analysed by means of what was considered within the research process to be a validated, reliable protocol (OPIR), which could produce an accurate portrayal of the classroom activities. The accuracy of these findings was assessed during phase two of the research when each of the participating lecturers reflected on the findings. During the coding and interpretation of the data 'direct interpretation' was employed as validity strategy (Creswell, 2003). When applying the technique of direct interpretation the "researcher looks at a single instance and draws meaning from it without looking for multiple instances" (Creswell, 2003, p. 154).

Internal validity, or credibility, specifically assesses the accuracy of the information and whether it matches reality (Creswell, 2003). To improve the accuracy of the profiles generated after applying the observation protocol to the video-recorded data (the descriptive validity), two people were used to analyse the video recorded data in order to achieve "investigator triangulation" (Johnson, 1997, p. 283). Strategies to improve interpretive validity include participant feedback and the use of "low inference descriptors" in the observation protocol (Johnson, 1997, p. 283). As mentioned earlier, the observation protocol (OPIR) emphasises manifested classroom descriptions of the representations used by the participating lecturers and not latent inferential observations. Further validation of the accuracy of the products of applying the observation protocol to the video data were obtained during the interviews with each of the participants where they were asked to validate the product as a fair representation of their instructional practice with regard to the use of representations in their introductory physics classes. Theoretical claims are substantiated where possible with transcripts to provide a rich and meaningful context.

One of the canons of design-based research is the study of the designed artefact in its real-life context. This requires of the study to be ecologically valid. Ecological validity is concerned with “the degree of naturalness of the research location and situation” (Plowright, 2011, p. 30) or in the words of Bryman (2012, p. 48) “the question of whether social scientific findings are applicable to people’s every-day, natural social settings”. Ecological validity’s importance in case study research is linked to the key case study research tenant of studying cases in their real-life context (Yin, 2014), linked with the aim of practical usability (Swanborn, 2010).

The data for the study data was collected in ecologically valid settings, i.e. within classes determined by the programme for which the students were registered and taught by the lecturers assigned to teaching on these programmes (Salkind, 2000). The researcher did not alter any of the activities to be investigated. Care was taken to capture these actions as part of the natural flow of the teaching activities. During the classroom observation the researcher sat at the back of the class so as not to distract the students, or the lecturer. As noted earlier, the video-camera was positioned at the back of the class and the students were assured that they would not be identifiable in the video since the camera was zoomed in to only capture the lecturer and either the green board or the overhead projector screen to capture the instructional use of representations by the lecturers. To further improve the ecological validity of the data, video stimulated recall was used as technique during the semi-structured interviews. Providing the lecturers with an artefact of their actual instructional practice and allowing them to reflect on their actions not interrupting their classroom schedule, further contributed to the ecological validity of the study.

The last criterion considered was that of usefulness. Usefulness or consequentiality of the research is somewhat akin to external validity and generalisability (Barab & Squire, 2004). Research which is generalisable enables the researchers to bring the results and implications of a study into more general use; "[h]owever, design-based research literature agrees completely that the findings of design-based research cannot be generalised from a sample to a large population" (Alghamdi & Li, 2013; Barab & Squire, 2004, p. 7; Plomp, 2007) based on the "highly contextualised research agenda and its heavy reliance on thick description for data analysis" (Alghamdi & Li, 2013, pp. 7-8). The above argument need to be interpreted in the context of the emphasis placed in design-based research "on understanding the value of a theory through its consequences on naturalistic systems" (Barab & Squire, 2004, p. 8). Barab and Squire (2004, p. 8) cite Messick's notion of evidence of consequential validity stating that "the validity of a claim is based on the changes it produces in a given system. These changes or consequences can then be considered evidence in support of validity". Embracing the notion of consequential validity, design-based researchers need to:

"draw connections to theoretical assertions and claims that transcend the local context. This involves not simply sharing the designed artefact, but providing rich descriptions of context, guiding and emerging theory, design features of the intervention, and the impact of these features on participation and learning"

(Barab & Squire, 2004, p. 8).

8.2 Reliability

Given the variability that is possible when scoring an observation instrument and that some degree of judgements is required scoring observational data (Leech, Barrett, & Morgan, 2005) it is important to verify the consistency of the evaluations. Reliability in this research is taken as an indication of the degree of consistency in the execution of the research process (Silverman, 2005). Two reliability or consistency strategies were employed to ensure that the answer to the above stated question is affirmative, namely internal reliability and inter-rater reliability. Internal reliability refers to the degree of how independently of the researcher the data were collected and analysed (Bakker & Van Eerde, 2014). It focuses on the question proposed by Tashakkori and Teddlie (2003), namely: Did I accurately captured or represent the phenomenon? To reduce bias during data collection, the classroom observations were video recorded, while the interviews were digitally recorded. To increase the internal reliability during the analysis of the video data using the observation protocol designed, the "dual-coding" analysis strategy was implemented where two coders (the researcher and an independent research assistant) coded the video data (Gerrish & Lacey, 2010, p. 401).

To enhance the consistency of the claims made based on observational data the aspects of inter-rater consistency or reliability was addressed. Inter-rater reliability (IRR) or the degree to which two or more observers of the same behaviour agree in terms of their coding of relevant behaviour on the observation schedule, was established between the two coders used to code the video data of the five participant lecturers using the designed observation protocol, accompanied by the explanatory key. A training session was conducted with the second coder to ensure that categories contained in the observation protocol with its accompanying explanatory key were sufficiently defined and mutually understood to ensure that all coders will reach agreeable conclusions (Kondracki et al., 2002).

The video generated of a lesson of one of the participants was conveniently selected for a first round of independent coding by both the coders, after which a discussion meeting was held where the various aspects of the coding process, the clarity of the protocol key, and the differences in codes assigned, were discussed. The results of this process are documented in chapter four. The simultaneous coding of the same record allowed the coders to practice, but it also enabled the results to be used to establish a measure of IRR. The coding was followed by an educational discussion about the matching and mismatching of the codes. Consensus was reached between the two coders on the interpretation of the protocol after which the observation protocol and the coding key were refined and finalised.

To ensure a good degree of stability in coding over time, or, all the video was coded by the same two coders (Kondracki et al., 2002). Reliability of this study was further enhanced by the focus on low-inference manifested descriptors in the observation protocol (Silverman, 2005).

9. RESEARCH ETHICS AND CODES OF PRACTICE

While endeavouring to achieve the objectives of the research, the researcher attempted to conduct the research in a manner that did not interfere or conflict with any participant. The details of ethical practices employed in this study are discussed in more detail below, following the layout of Franklin (2012). The first ethical approval was sought from the Research Ethics Committee (Human) of Nelson Mandela Metropolitan University (reference no H13-EDU-ERE-004). Documentary proof is provided in Appendix A.

Ethics of consent: The research was conducted on the basis of lecturers volunteering to participate in the study. The data collected for this project have not been of a highly sensitive nature, politically, socially or physically. Regardless of this, it is important to sustain a notion of respect for every individual involved and to obtain participants' cooperation and consent to use the information obtained in this research. The purpose and nature of the research is clearly stated in the information sheet that accompanied the consent form that required lecturers to provide written consent (see Appendix A).

Ethics of access: The following gatekeepers were consulted to gain access to the participants in their real-life context, namely their introductory physics classrooms: the Heads of the academic departments Mechanical Engineering and Physics where the lecturers are located. An information session was organised with the lecturers in their departments and volunteers invited to participate in the study.

Ethics in data collection: Participants in this study will all form part of intact class groups formed by the NMMU as part of their normal academic administrative processes. The lecturers could withdraw from the study at any point.

Ethics of transparency, anonymity and confidentiality: Having video recorded data as the main data set, this study was faced with tension between the concepts of transparency, anonymity and confidentiality, so aptly described by Franklin (2012).

> *"On the one hand academic research is about leaving a clear train. On the other hand, most social research with human subjects is based on privacy whereby informants' identities and their pronouncements (written or spoken) are treated anonymously unless they provide consent to be named"*
>
> (Franklin, 2012, p. 81).

Although confidentiality is a particular challenge due to the non-anonymous nature of video-data, confidentiality can be protected (Fitzgerald, 2011). Written consent was specifically obtained from the lecturer for the video recording of their instructional practice (see Appendix A). Anonymity of all participants was as far as possible preserved throughout the process. All identifying information about names has been removed and alias names used during the presentation of the individual profiles to protect participant confidentiality. Access to the raw video footage has been restricted to only include the researcher, the research assistant and supervisor. The video clips that served as evidence in the web-based resource was made accessible only to the particular individual lecturer. Each participant had access to the generic opening pages, their own profile and the general combined profiles of all the participants. This was achieved by providing each participant with a unique URL, restricting access to the other profiles. The researcher and the panel of experts that viewed the video clips of the classroom practice of the lecturers are bound to maintain confidentiality to protect the identities of the participants. The identity-based information (the video clips of the classroom practices) is kept in a password-protected file on an external storage device stored in a safe and secure location and will be kept for a period of 5 years after publication of the thesis on the researcher’s computer.

10. CHAPTER SUMMARY

This chapter provided an overview of the philosophical assumptions that underpinned the design-based research approach chosen to answer the research questions posed in chapter one. An overview of design-based research was followed by a rationale for choosing this approach. Design-based research was presented as a research approach that studies phenomena within naturalistic settings with a clear goal of impacting practice and advancing theory, in this case around reflective practice. A web-based artefact grounded in the principles of design-based research was developed with the clear goal of facilitating the growth and development of reflection on the instructional use of representations by introductory physics lecturers. The design focus on question driven research, the notion of abduction, and the reasons for choosing a case-study approach to illustrate the different uses and instructional affordances displayed, and the levels of stimulated reflection displayed by the individual lectures, are all considered.

A description of the data collection methods, the analysis and procedures in relation to the quality of the design and the interpretation of the data followed. Issues of sampling, data generation instruments and data generation techniques are described and the complementary role of data collection and analysis is highlighted and descriptions of the multiple levels of coding which support the development of the case studies are given. The design of the protocol and the complementary role of data collection and analysis are highlighted. Detailed descriptions of the multiple levels of coding are provided. The analysis, organisation and identification of emergent themes of the video data and reflective interviews are considered, as are issues of validity and reliability. Validity was considered as consequential and framed within a utility discourse. Finally, the ethical aspects and codes of practice of the collection and use of video data in an educational setting were considered. The next chapter will present the results of the instantiation of the observation protocol as it was applied to the video data generated of the five participating lecturers, followed by the validation of this protocol.

CHAPTER FOUR

RESULTS

1. INTRODUCTION

Chapter three introduced and justified the methodological approach adopted during this research and the results of these processes are presented in this chapter. The results of the grounding phase, which involved the identification and formulation of a research problem followed by the grounding of the problem in a theoretical framework, is discussed, as are results of the conceptualisation phase, which involved the design and development of the artefacts proposed to solve the research problem.

Three artefacts were constructed in the context of this research. These artefacts are (i) a construct (explanatory key to the observation protocol containing the terminology in which the problem and solution to the problem is communicated), (ii) an observation protocol for the description of the instructional use of representations by introductory physics lecturers, and (iii) the instantiation of the observation protocol using video data of classroom observations and data which resulted in profiles of lecturers' representational repertoire and instructional practice using representations. The overarching framework that was designed from analysis of the three artefacts was assessed during the validation stage for its suitability for its intended purpose of stimulating and influencing reflection by lecturers on their practice when using representations in physics classes.

2. GROUNDING PHASE

As explained in chapter three the purpose of the grounding phase of the study was to identify and formulate the research problem with its associated research objectives that would allow the artefact to address the problem formulated. The identification of the research problem and objectives have taken place in chapter one. A further activity in this phase involves grounding the proposed artefact in the existing knowledge base relevant to the research problem identified. The review of the knowledge based related to the instructional use of representations in physics and reflective practice by physics lecturers was reported in Chapter two.

3. CONCEPTUALISATION PHASE

This section addresses the results of the various activities related to the conceptualisation phase of the research design. The methods employed to generate the required data and the issues associated with the use of such methods were discussed in chapter three. The conceptualisation phase resulted in a reference manual for the observation protocol (see Appendix B) and a web-based resource to illustrate and support the outcome of applying the protocol to video data of classroom observation (see the Compact Disc [CD] supplied with this manuscript for all five web-based resources for the five lecturers and to see the video links). These two major products of the conceptualisation phase are discussed in more detail in the sections and sub-sections to follow.

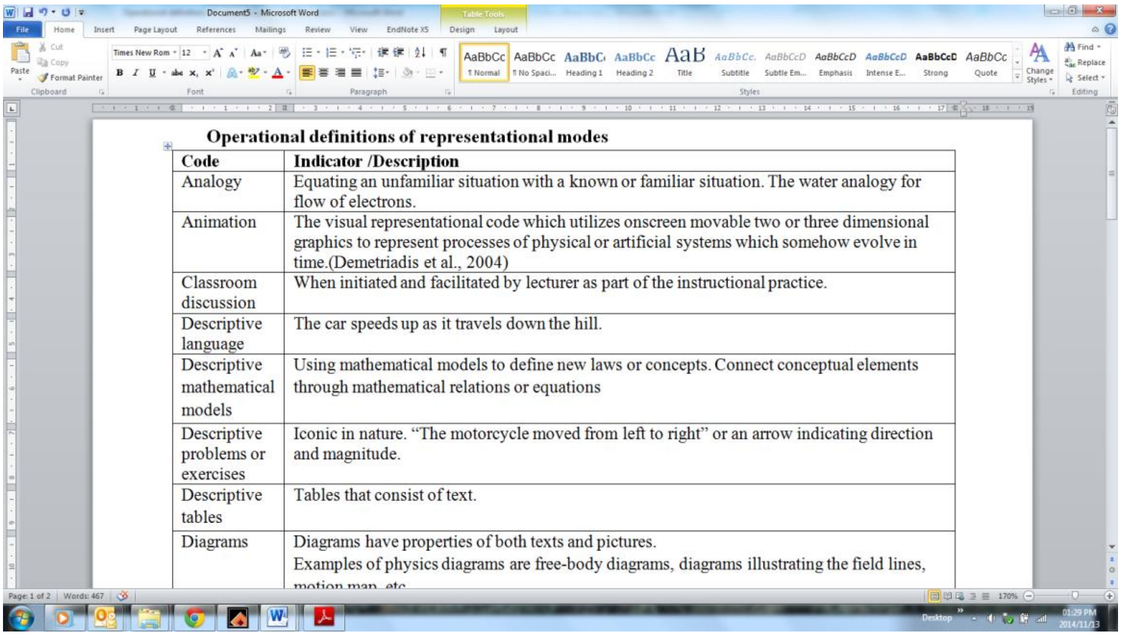
3.1 Development of the reference manual for the OPIR

The reference manual was the first research output of this research project. The manual is considered to be a designed artefact in the context of design-based research (Hevner et al., 2004) as it entails (i) a construct containing vocabulary, symbols, abstractions and representations linking theory and practice, (ii) instantiation of the construct and methods used, and (iii) operational definitions of the codes contained (see Appendix B). The construct, instantiation and operational definitions were refined through iterative cycles of implementation, discussion and reflection. These refinements are presented in the sections to follow.

Construct development

The construct contains the list of codes used in the observation protocol with either a description or a definition (and on occasion an illustration) for each of the codes, keeping in mind that the purpose of the construct is to operationalise the manifested actions of the lecturers in a face-to-face lecture (as opposed to for example practical sessions). A preliminary construct for the observation was developed during the grounding phase based on descriptions and definitions found in literature.

After the first iteration the format of the list of operational definitions were changed to improve its user-friendliness. The first format was an alphabetic list of concepts or codes with a description for each code (see Figure 4.1). The alphabetic order of the list of definitions did not follow the same flow as the items in the observation protocol, which made it difficult to find the definition of a particular concept in-between the other concepts. It was decided to imitate the flow of the codes in the observation protocol by using a numbering system to link the same code on the observation protocol with the definition of the code in the list of definitions.

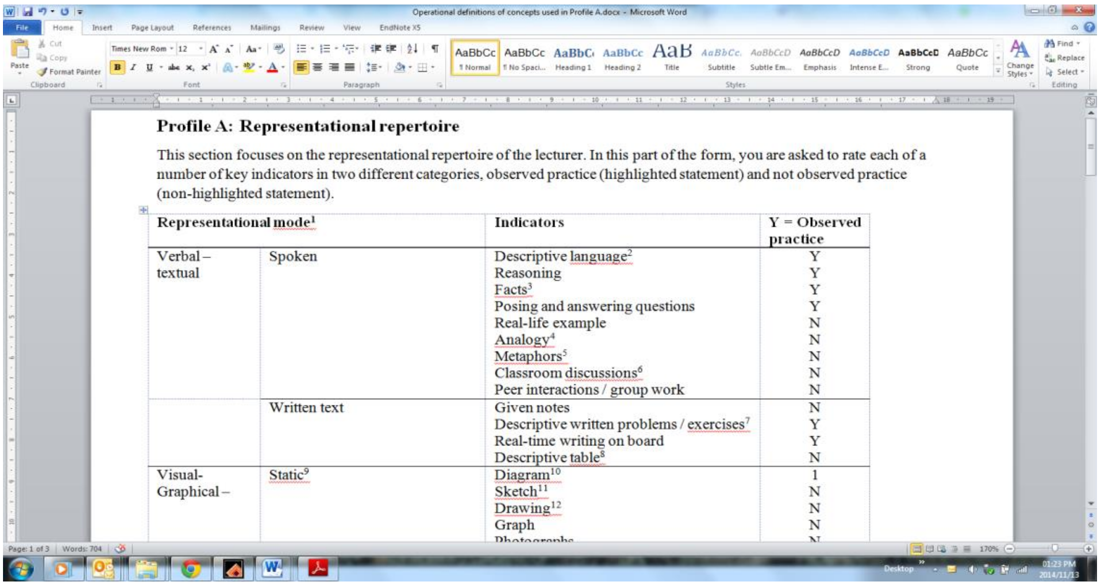


Operational definitions of representational modes

Code	Indicator /Description
Analogy	Equating an unfamiliar situation with a known or familiar situation. The water analogy for flow of electrons.
Animation	The visual representational code which utilizes onscreen movable two or three dimensional graphics to represent processes of physical or artificial systems which somehow evolve in time.(Demetriadis et al., 2004)
Classroom discussion	When initiated and facilitated by lecturer as part of the instructional practice.
Descriptive language	The car speeds up as it travels down the hill.
Descriptive mathematical models	Using mathematical models to define new laws or concepts. Connect conceptual elements through mathematical relations or equations
Descriptive problems or exercises	Iconic in nature. "The motorcycle moved from left to right" or an arrow indicating direction and magnitude.
Descriptive tables	Tables that consist of text.
Diagrams	Diagrams have properties of both texts and pictures. Examples of physics diagrams are free-body diagrams, diagrams illustrating the field lines, motion map, etc.

Figure 4.1: A screen shot illustrating the first format of the construct – codes organised alphabetically

The superscript one found next to the concept 'representational mode' on the observation protocol (see screen shot in Figure 4.2) therefore correlates with the number 1 entry in the operational definitions key (see screen shot in Figure 4.3).



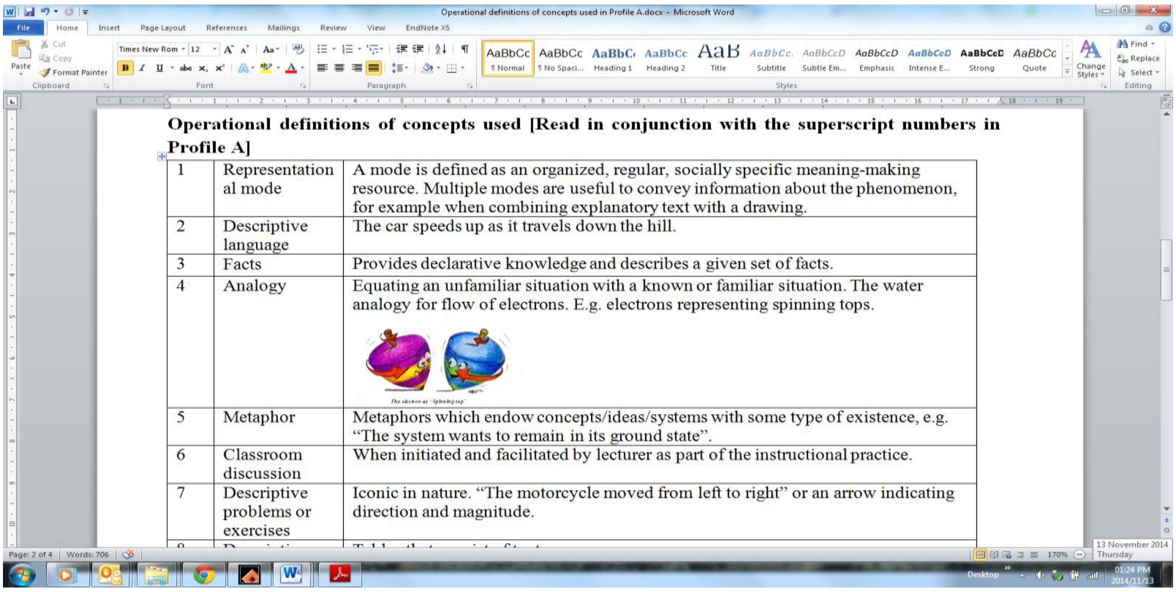
Profile A: Representational repertoire

This section focuses on the representational repertoire of the lecturer. In this part of the form, you are asked to rate each of a number of key indicators in two different categories, observed practice (highlighted statement) and not observed practice (non-highlighted statement).

Representational mode[1]		Indicators	Y = Observed practice
Verbal – textual	Spoken	Descriptive language[2]	Y
		Reasoning	Y
		Facts[3]	Y
		Posing and answering questions	Y
		Real-life example	N
		Analogy[4]	N
		Metaphors[5]	N
		Classroom discussions[6]	N
		Peer interactions / group work	N
	Written text	Given notes	N
		Descriptive written problems / exercises[7]	Y
		Real-time writing on board	Y
		Descriptive table[8]	N
Visual-Graphical –	Static[9]	Diagram[10]	1
		Sketch[11]	N
		Drawing[12]	N
		Graph	N

Figure 4.2: A screen shot illustrating the superscript numbers linking the operational definition of the particular code to the code in the observation protocol

This simplified the coding process of the video data and resulted in the format used in the paper-based reference manual (see Appendix B).



Operational definitions of concepts used [Read in conjunction with the superscript numbers in Profile A]

1	Representational mode	A mode is defined as an organized, regular, socially specific meaning-making resource. Multiple modes are useful to convey information about the phenomenon, for example when combining explanatory text with a drawing.
2	Descriptive language	The car speeds up as it travels down the hill.
3	Facts	Provides declarative knowledge and describes a given set of facts.
4	Analogy	Equating an unfamiliar situation with a known or familiar situation. The water analogy for flow of electrons. E.g. electrons representing spinning tops.
5	Metaphor	Metaphors which endow concepts/ideas/systems with some type of existence, e.g. "The system wants to remain in its ground state".
6	Classroom discussion	When initiated and facilitated by lecturer as part of the instructional practice.
7	Descriptive problems or exercises	Iconic in nature. "The motorcycle moved from left to right" or an arrow indicating direction and magnitude.

Figure 4.3: A screen shot illustrating the list of operational definitions organised according to the numbers allocated to the code in the observation protocol

The second iteration of the design resulted in a set of web-based resources. Instead of including a table with a list of operational definitions (the format of the paper-based Reference manual) the definitions were incorporated in the Representational Repertoire profile as a blue information icon next to the relevant code that reveals the explanation or definition when the user clicks on the icon. Figure 4.4 illustrates this integration of the construct in the web-based set of resources (see section 3.2.3 for more detail about the web-based resources).

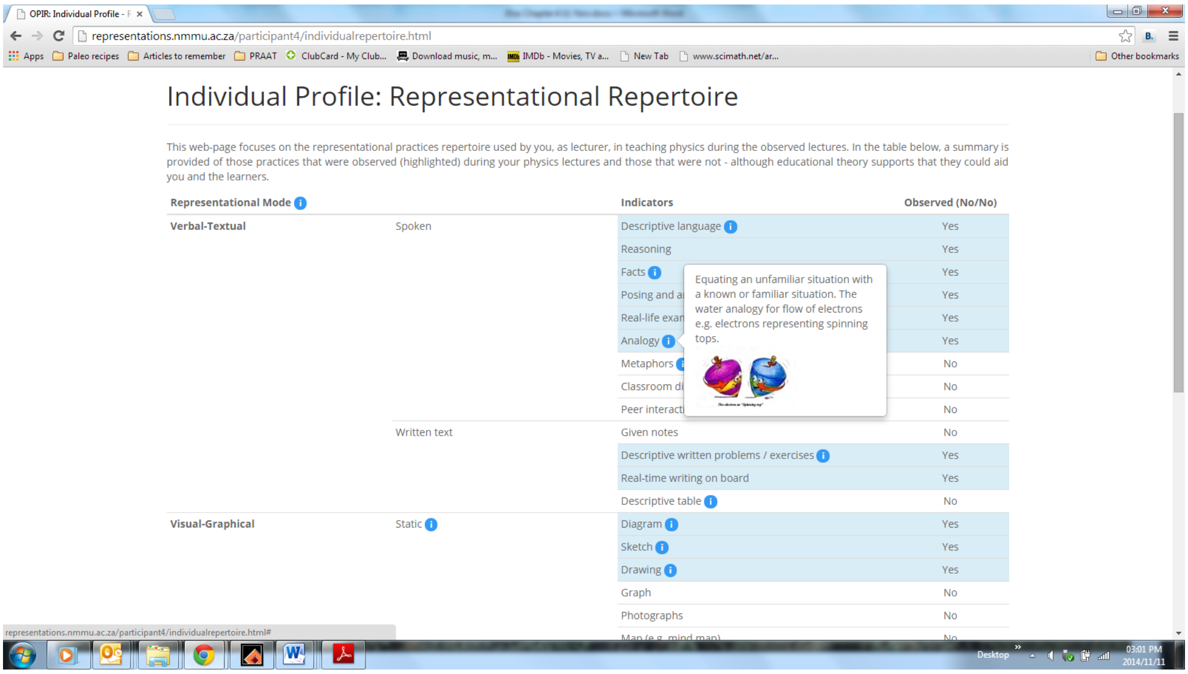


Figure 4.4: A screen shot illustrating the inclusion of the definitions in the web-based profile of a lecturer's representational repertoire

In the section to follow, the development of the observation protocol is discussed, although the development of the construct and the protocol was intertwined and the separation is only for organisational purposes.

Observation Protocol development

The first draft of the observation protocol was developed during the review of the literature and contained four categories: nature of the representations used; function of representations (with sub-categories including complementary function, constructive function and constraining function); instructional affordance of the representations (with sub-categories cognitive, social and material affordances); and instructional environment. As the understanding of the nature of the research problem became clearer, I adapted a set of criteria proposed by Wainwright, Flick, Morrell, and Schepige (2004) to assess the validity of the categories and codes captured in the initial protocol. The criteria applied were: (i) only propositions that address the use of external representation, (ii) only aspects that can be observed should be included in the protocol, (iii) the protocol should contain statements that describe the practices of the lecturers and not the quality of the instruction, and as such no Lickert scale questions were included, and (iv) the protocol must be manageable, assuming a reasonable amount of time available to use it (Wainwright et al., 2004).

This resulted in the removal of the categories ‘function of representations’ and ‘instructional affordance’ as they were latent characteristics and not manifested characteristics of the instructional use of representations. The label for the category ‘nature of representations’ was changed to reflect the label ‘representational repertoire’ as it is a better description for the various representational modes used by the lecturer. Similarly the category ‘instructional environment’ was redefined as ‘Instructional strategies” to better reflect the codes included under the category (see Figure 4.5).

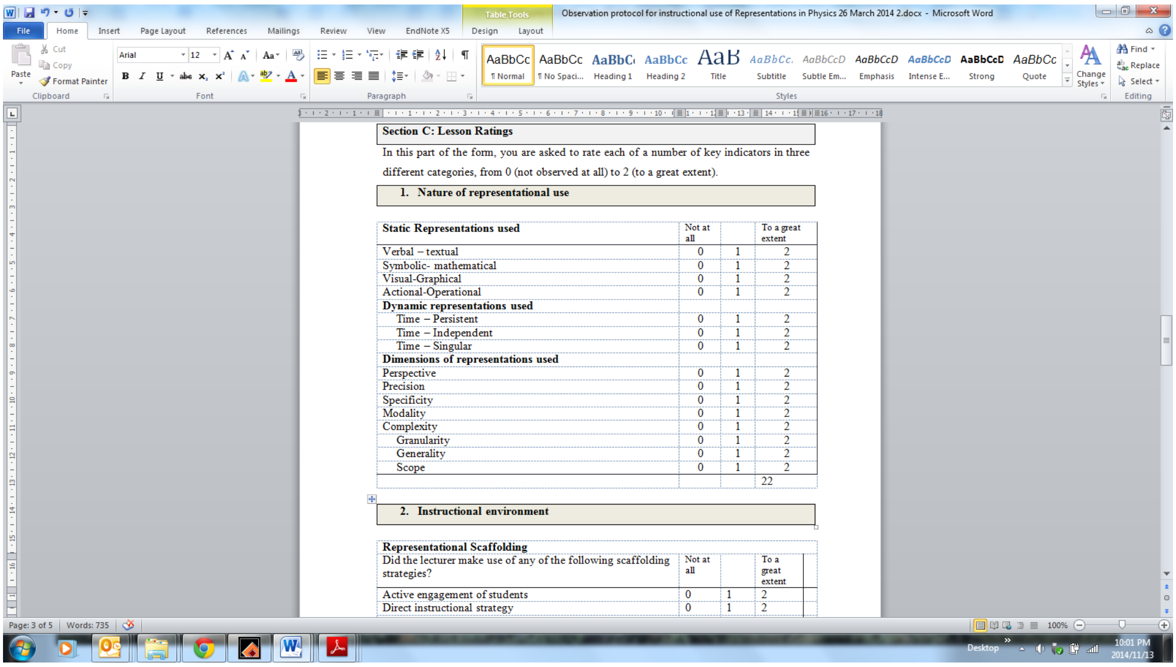


Figure 4.5: A screen shot illustrating the first draft of the observation protocol

A background section was added to the protocol to capture the elements of classroom instruction, namely the use of specific teaching methods (e.g. lecture, small-group discussions, etc.), the types of cognitive engagement students experience in the class, and the use of instructional technology (e.g. data projectors and chalkboards) (Hora & Ferrare, 2014). This resulted in a protocol consisting of three main sections: background information and context of the observed lesson; the representational repertoire of the lecturer; and the instructional strategies used during the use of representations in introductory physics classes (see reference manual in Appendix B).

Assessment of observation protocol and list of operational definitions

Given the variability that is possible when scoring an observation instrument and that some degree of judgements is required scoring observational data (Leech et al., 2005) it is important to verify the consistency of the evaluations. Inter-rater reliability (IRR) was chosen as an indicator of this consistency. In order to establish the IRR of the observation protocol, answers were sought to the following two questions.

- Is the coding stable across different situations?
- Is there inter-rater reliability of the OPIR?

As explained in chapter three (section 8.2) the stability of the coding across the different participants' video data was evaluated using IRR as indicator. During the training session provided to the research assistant, the video data of one of the participants (chosen for convenience as it was the first observation completed) was independently coded by both the researcher and the research assistant. The results of the coding were inspected for possible disagreements or variation in interpretation of the explanatory key, as well as testing the quality of the category descriptions in the observation protocol in terms of applicability. It was found that some of the descriptions and definitions some of the labels for representational modes or their definitions contained in the construct were too vague and as a result these were refined. For example, it became necessary to distinguish between a descriptive table and a numerical table, or change the label for a code 'conversational language' to 'descriptive language' (adding each codes appropriate definition or description in the list of operational definitions). The regular discussions between the two coders (the researcher and a research assistant) resulted in a list of operational definitions upon which consensus was reached in terms of the clarity of the code labels, as well as the definitions and illustrations provided to allow the two coders to code a video segment without any difference in interpretation between the two coders.

In terms of the validity of the observation protocol, a number of changes were made as a result of the discussions between the two coders. These changes are documented in Table 4.1. Some minor editorial re-shuffling was also made after each application of the protocol. Eventually the observation protocol and the explanatory key were refined to the point that the last coding was able to take place with no difference between the two coders, which suggested that an acceptable degree of stability across the five sets of video data had been achieved. Thereafter all the video data were coded by the same two coders (the researcher and the research assistant) after which only periodic checks were made to ensure continued consensus.

Table 4.1: Summary of most important changes made to the observational protocol and explanatory key

Representational repertoire (Section 2)	
verbal-textual (spoken)	• "Conversational language" changed to "Descriptive language" • "Reasoning" was added
Verbal-textual (written text)	• "Given written problems" changed to "Descriptive problems/exercises" • "Descriptive table" was added as an additional code
Visual-Graphic (static)	• Delete "Graphical table"
Visual-Graphic (dynamic)	• Added "simulation" as indicator
Symbolic-mathematical	• Added "algebraic expression"
Actional-operational	• Added experimental manipulations • "role play" was moved from the complex category to the actional-operational category
Complex	• Delete "Flash animation", "video - animation and replace with one indicator "video" to delete overlap.
Instructional practice (Section 3)	

	• The indicators were re-organised and re-grouped to have three main practices, with their sub-practices and indicators.

3.2 Instantiation

A case study approach was used for the instantiation phase of the observation protocol with the five participating lecturers who participated in the validation process representing the cases. The findings of the case studies are provided not to indicate specific issues of representational use between lecturers, but to illustrate the types of profiles that can be generated, and to help illuminate the possibilities that such profiles may offer. As described in chapter 3, the instantiation phase resulted in a set of profiles on the instructional use of representations by these five lecturers. The instantiation went through two cycles (see Figure 4.6). Firstly, the context within which each lecturer (all of whom were male) operated is briefly described, where after short examples of actual profiles are offered.

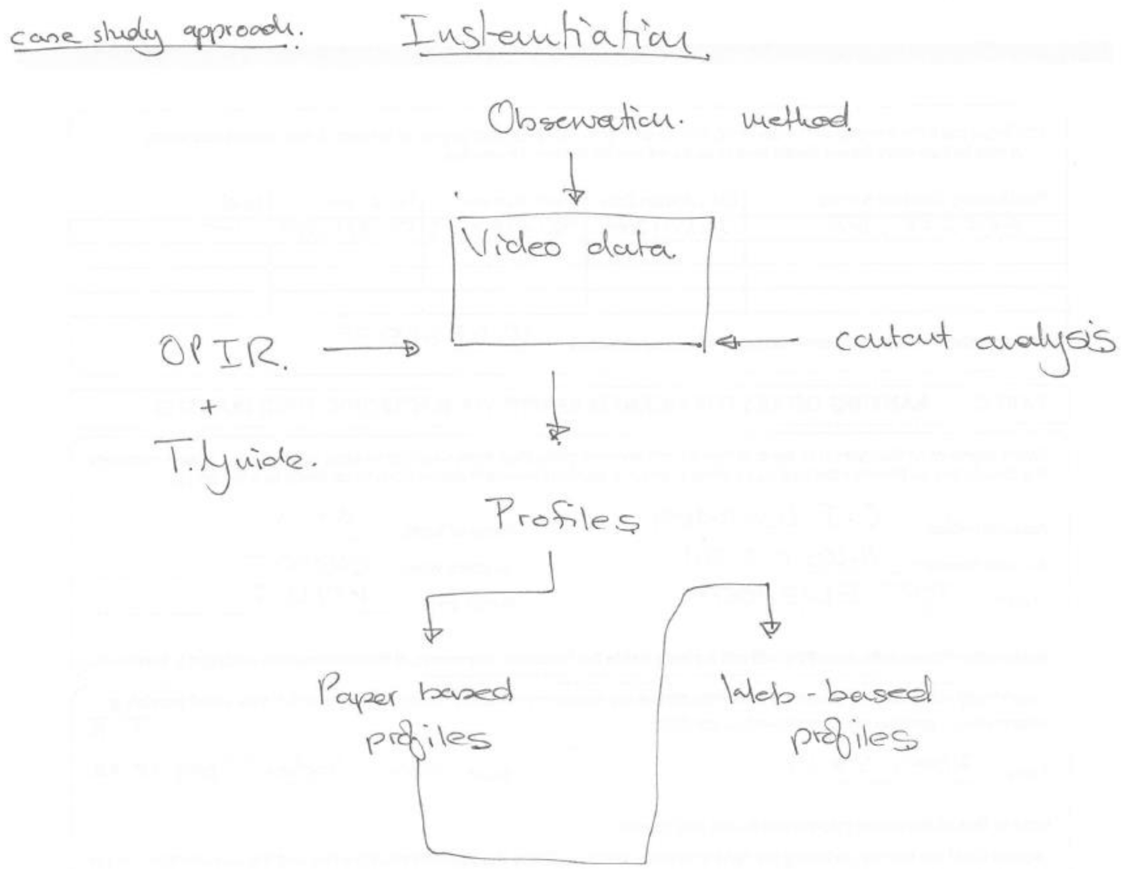


Figure 4.6: The researcher’s conceptualisation of the instantiation phase in this study

3.2.1 Contextual findings

While emphasising the link between context and the teaching of physics, Redish (1994, p. 803) comments that “[a] typical university course is a complex structure” involving physics content, a lecturer, a classroom, a laboratory and perhaps teaching assistants or student assistants complemented by a particular set of students. Lecturers shape and are shaped by the contexts in which their teaching takes place, and if one is to understand possible drivers of the instructional use of representations one must consider the teaching contexts of individual lecturers (Redish, 1999).

All of the five participants in this study have either a Masters or a Doctoral degree in physics or mechanical engineering. None of them has received formal training in education. Lecturers 2 and 5 taught students enrolled for an engineering qualification, while lecturer 3 taught pure BSc (Physics), pure applied (BEng) and Physical science education students. Lectures 1 and 4 taught groups of interdisciplinary students where physics was not considered one of the major subjects in the qualification. Research has indicated a significant difference in the 'genetic make-up' of the two associated disciplines, namely "hard pure knowledge disciplines" of which physics is an example and "hard applied knowledge disciplines" such as engineering (Neumann et al., 2002, p. 406). This genetic make-up influences the basic beliefs around teaching (and learning) and what is happening in the classroom. In order to understand the context from an instruction point of view, the framework provided by (Neumann et al., 2002) in which they distinguish between hard pure knowledge disciplines such as physics and hard applied knowledge disciplines typified by engineering, in terms of five aspects relevant to this study, namely the general characteristics of the curriculum, the lecturer, the cognitive priorities, teaching methods and their expectations of the students. Physics (a hard pure knowledge subject) typically has "a cumulative, atomistic structure, concerned with universals, simplification and a quantitative emphases" (Neumann et al., 2002, p. 406).

General overview of the classroom arrangements

All the lecturers had what can be described as traditional classroom arrangements where students are seated all facing towards the front of the classroom (Close, Close, McKagan, & Scherr, 2010). Lecturers two, three and four taught in the same venue in the Physics Department building with a laboratory and the assistance of a laboratory assistant within easy reach. The venue is equipped with fixed chairs and desks arranged in a typical flat lecture style configuration. The desks are a long solid desk with fixed swivel chairs in a flat classroom. The classroom is also equipped with a mounted data projector and screen, supplemented with a chalk board.

Lecturer one taught his class of 50 students in a general flat lecture room (i.e. one that is used by a variety of programmes across a broad spectrum of programmes across the university) with loose tables and chairs arranged in rows facing to the front of the classroom. The class is slightly overcrowded (little space between students) and is equipped with an interactive whiteboard that is faulty and used as a ‘normal’ whiteboard supplemented occasionally with an overhead projector. If the lecturer wishes to use a data projector as instructional resource, it has to be booked at the central media services of the university and is set-up only for the particular session for which it was booked. The lecturer does not have readily access to a laboratory assistant for both setting up and breaking up of equipment when it is used during instruction. Since the same venue is used for other classes throughout the day, and given the over crowdedness of the classroom, storing equipment in the class to be taken away at another time, is not a viable option.

Lecturer five taught a group of nearly 100 engineering diploma students in a venue that can be described as a typical auditorium style (raked). The venue is elevated towards the back with the chalk board situated in the front of the classroom. There is no mounted data projector in the venue. As similar procedure as described for lecturer one need to be followed when the lecturer wants to use a data projector in his teaching. The chairs are fixed swivel chairs with a single long bench stretching from left to right with walkways on the side of the seating. Table 4.2 provides an overview of the contexts in which the individual lecturers operated. More detail around the individual lecturers is provided in the sub-sections to follow.

Table 4.2: Physical contexts within which the individual physics lecturers operated

	Lecturer 1	Lecturer 2	Lecturer 3	Lecturer 4	Lecturer 5
Academic Department of lecturer	Physics	Physics	Physics	Physics	Mechanical Engineering
Home discipline of students	Health Sciences	Mechatronic Engineering	Science Education Engineering	Construction Management Health Sciences	Mechanical Engineering
Size of classes observed	<50	<100	>100	<100	<100
Seating arrangements	Loose tables and chairs	Fixed seats	Fixed seats	Fixed seats	Fixed seats
Instructional technology used	Whiteboard	White board PowerPoint and other digital slides	White board PowerPoint and other digital slides	White board PowerPoint, digital slides, Video clips	Whiteboard

Lecturer 1

The module observed forms part of one of the compulsory first year subjects for students registered for the qualification National Diploma Radiography (diagnostic). The admission criteria for this qualification are an Admission Points Score (APS) of 32 with a minimum of 30% for Mathematics and Physical Science in their National Senior Certificate (NSC). The APS system allocates point values to the levels of achievement obtained in the NSC subjects.

Lecturer 2

The students enrolled in this course are BEng Mechatronic students who have all successfully completed Physical Science as subject at grade 12 level (it is a prerequisite for admission). The admission criteria for this qualification require a minimum APS score of 38, with a minimum of 60% for Mathematics and Physical Sciences in their National Senior Certificate (NSC). The class size was about 70 students.

Lecturer 3

The students enrolled for this physics module are BSc students, BEd students and BEng Mechatronic students (the same group observed with lecturer two). These are all degree qualifications, although the admission criteria for each of these sets of students are determined at different levels of achievement. For students enrolled for a BSc qualification the admission criterion is a score of 40 on the APA system with a minimum of 50% for Mathematics, whereas the other course only requires an APS score of 36 (BEd). This has the consequence that the class of about 150 students displays great variety in background knowledge and experience.

Lecturer 4

This class consists of a group of nearly 100 students who are enrolled in degree courses in the Life Sciences and in Construction Management. Although it is a compulsory subject for these students (as part of their respective qualifications), it is not compulsory to have taken or passed physical science as subject during their secondary schooling, resulting in great diversity in terms of the students background knowledge, expectations and areas of interest.

Lecturer 5

The students in this introductory physics course are enrolled in the National Diploma Mechanical Engineering. The admission requirements for this course are an APS of 34 with a minimum of 50% for both Mathematics and Physical Sciences on their NCS.

3.2.2 The first iteration of instantiation

Applying the observational protocol to the video data of each of the participants resulted in the generation of three profiles for each participating lecturer. The first profile represents the lecturer’s representational repertoire as observed during the observations compared to the modes of representation identified in literature as being beneficial to learning physics in introductory physics classes. The second profile entails a graph that compares the observed representational practices with practices documented in research literature as begin beneficial to physics instruction. The graph is followed by a third profile, namely a table that provides a classification of the lecturer’s instructional use of representations for introductory physics in terms of traditional and contemporary practice or research-based instructional practice. Specific examples of profiles generated are presented below.

Representational repertoire

The first profile (see Table 4.3) illustrates the representational repertoire of Lecturer 2, i.e. the representational modes that were used during the observed lessons. The instructional practice of the lecturers was rated as either observed (highlighted) or not observed practice (non-highlighted statements).

Table 4.3: Representational repertoire of Lecturer 2 as an example

Representational mode		**Indicators**	**Observed**
Verbal – textual	Spoken (V-S)	Descriptive language	Y
		Reasoning	Y
		Facts	Y
		Posing and answering questions	Y
		Real-life example	Y
		Analogy	N
		Metaphors	N
		Classroom discussions	Y
		Peer interactions / group work	N
	Written text (V-W)	Given notes	N
		Descriptive written problems / exercises	Y
		Real-time writing on board	Y
		Descriptive table	N
Visual-Graphical –	Static (V-S)	Diagram	Y
		Sketch	Y
		Drawing	Y
		Graph	N
		Photographs	N
		Map e.g mind map	N
	Dynamic (V-D)	Real-life example	N
		Animation	N
		Real-time graphs	N
		Simulation	N
Symbolic- mathematical	Descriptive (S-D)	Numerical table	N
		Algebraic expression / Equation	Y
		Formula	Y
	Explanatory (S-E)	Numerical table	N
		Algebraic expression / Equation	Y
		Formula	Y
Actional-Operational	(A-O)	Hand gestures	Y
		Hand demonstration	Y
		Role play	N
		Experimental manipulations	N
Material	Static (M-S)	Concrete physical model	Y
	Dynamic (M-D)	Real-life example	N
		Science demonstration	N
Complex	(C)	Video – real-life	N
		Integrated representation	Y
		Real-life Experiment	N

The complexity of the coding (or making judgements to compile a representational repertoire profile) is illustrated in a series of screen shots to follow. The screen shot of the chalkboard of one of the lecturers (Figure 4.7) illustrates the presence of a variety of representations, namely an explanatory mathematical formula, the use of a hand gesture to represent the right hand screw rule, and the use of an integrated drawing with force diagrams on a representation of an electric circuit. Each of these representations was coded individually as being observed on the observation protocol.

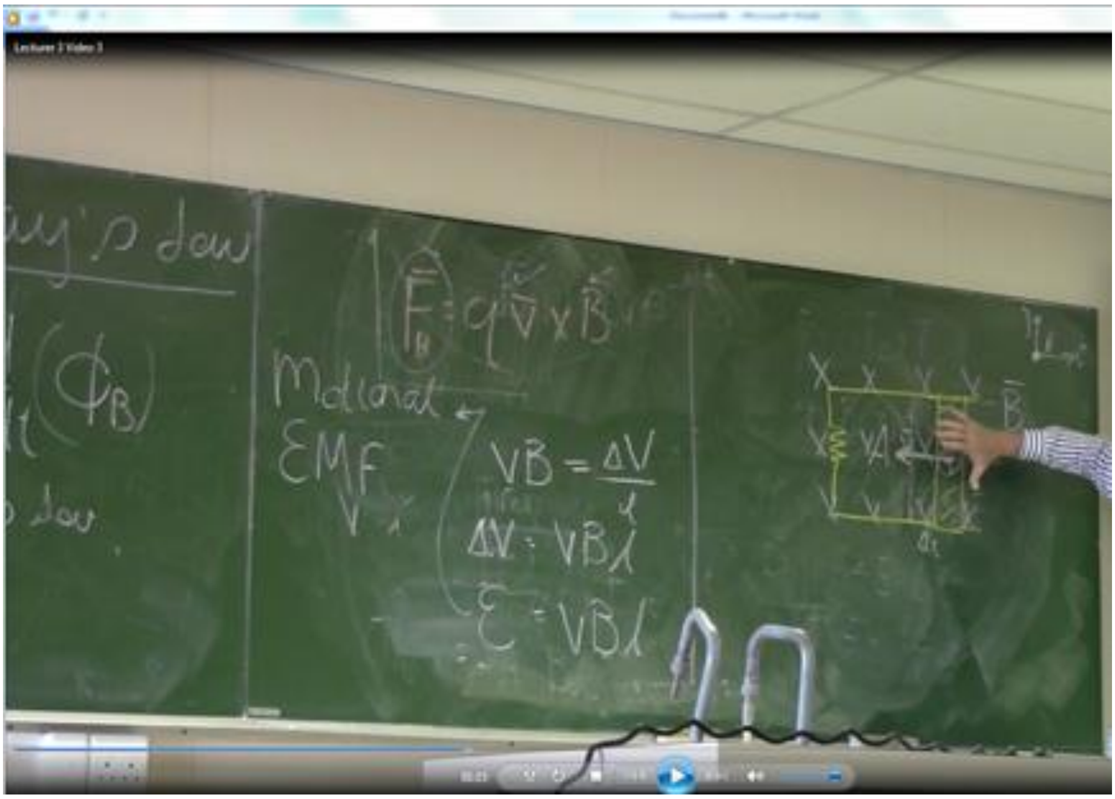


Figure 4.7: A screen shot illustrating a variety of representations used during an illustrative instructional event.

Figure 4.8 illustrates a digitally projected example of descriptive text - "sensation of loudness is logarithmic in the human ear". The same slide contains explanatory symbolic mathematical modes of representations where the equation for calculating loudness is provided.

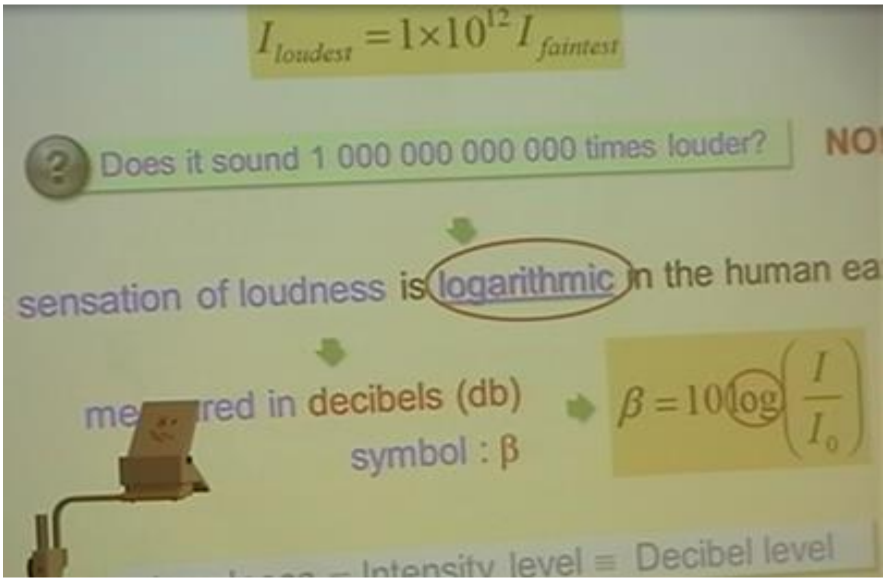


Figure 4.8: Example of representations coded as descriptive text and an explanatory mathematical formula

Similarly, Figure 4.9 illustrates a representation coded as a descriptive table.

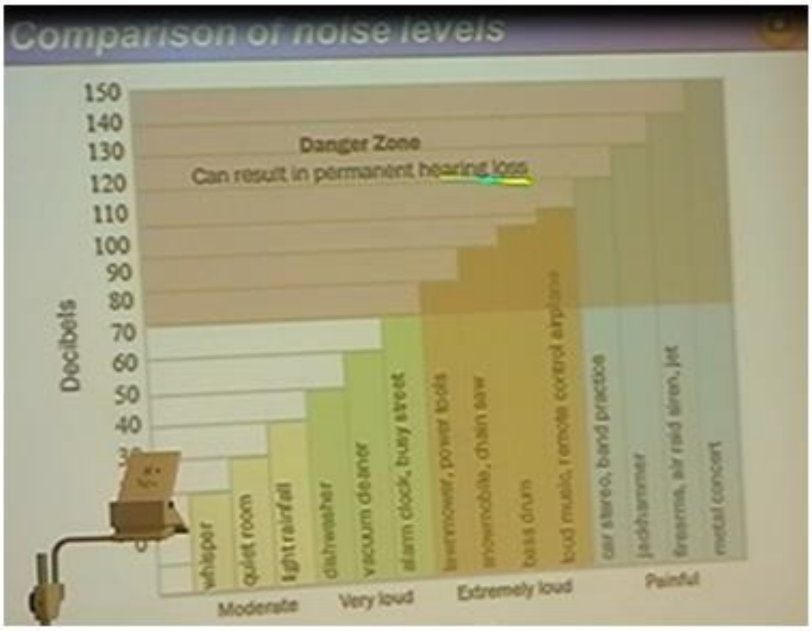


Figure 4.9: Example of a representation coded as descriptive text

Figure 4.10 contains a screen shot of a complex situation where the representations used was coded as representing the use of a graph; a circuit diagram; reasoning (the use of arrows to represent the flow of the electrons in the circuit); hand gestures (the lecturer illustrating a concept using his hand) and real-time writing on the board.

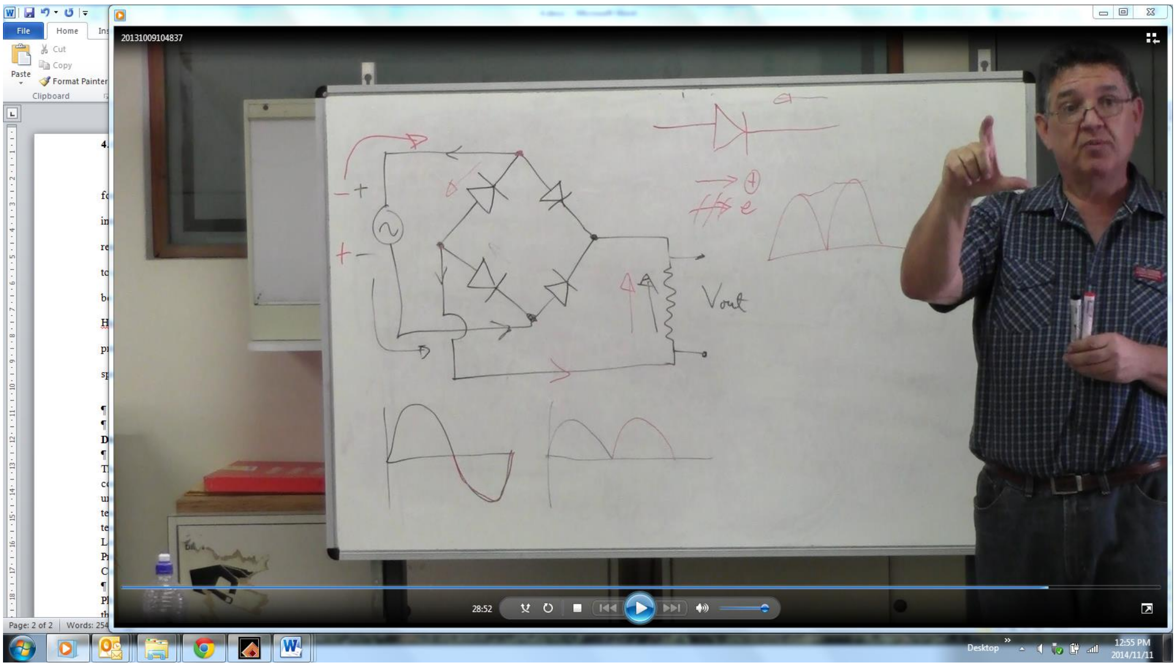


Figure 4.10: A screen shot of a complex event of representational use (used with permission from the lecturer)

Figure 4.11 illustrates an integrated representation where sketches are combined with diagrams and the use of descriptive mathematical models where the mathematical formula and equations are used to define new laws or concepts. It illustrates how the conceptual elements that are embedded in the 'Jaws of Life' are connected through mathematical relations and equations.

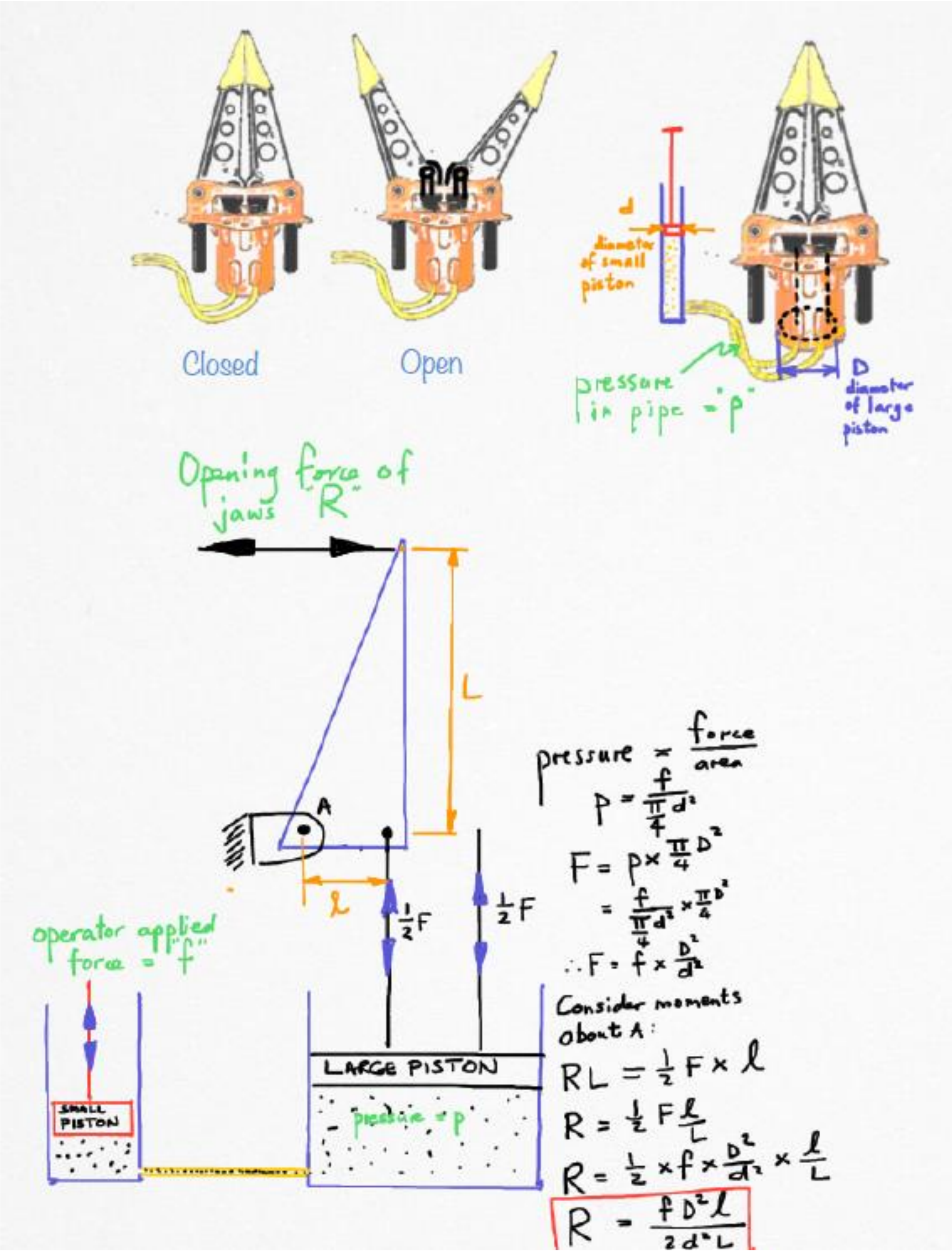


Figure 4.11: Example of a representation coded as an integrated representation

Representations used versus research based compendium of practices

The second profile was a represented graphically and compares the observed or manifested representational repertoire used by Lecturer 2 against the instructional representational practices documented in literature (Figure 4.12). The letters on the x-axis are abbreviations of the modes presented in table 4.4, for example V-S stands for the verbal-textual subcategory labelled spoken modes, etc. The modes of representation identified in literature as being beneficial for introductory physics instruction are labelled target research-based practice since these are the types of representations lecturers should be aiming to use, based on empirical evidence from physics education research.

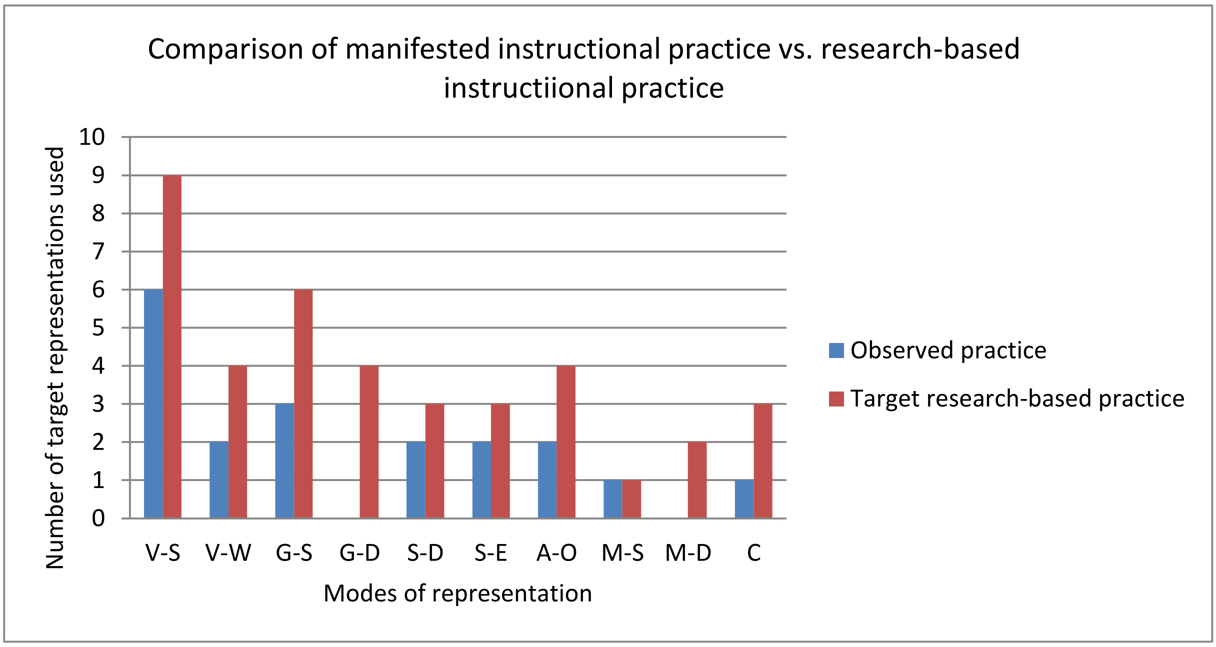


Figure 4.12: Comparison of manifested instructional practice vs. research-based instructional practice

Typology of practices

The typology in Table 4.4 is the third profile type, which strives to capture, in retrospect, the observer's overall interpretation of where the lecturer's practice may fall on each of the various representational modes in terms of being either generally traditional or more contemporary. The term contemporary describes research-based instructional methods or innovations that might be useful in the instructional use of representations.

Table 4.4: Typology of manifested instructional practice (Lecturer 2) (The yellow highlighted practices represent the observed or manifested practices.)

		Generally Traditional practice	Contemporary practice
Representational repertoire	Verbal – textual Spoken (V-S)	1. Descriptive language 2. Reasoning 3. Facts 4. Posing and answering questions	5. Real-life example 6. Analogy 7. Metaphors 8. Classroom discussions 9. Peer interactions / group work
	Verbal – textual Written (V-W)	1. Given notes 2. Descriptive problems/exercises 3. Real-time writing on board 4. Descriptive table	
	Visual-Graphical Static (G-S)	1. Diagram 2. Sketch 3. Drawing 4. Graph	5. Photographs 6. Map e.g mind map
	Visual-Graphical Dynamic (G-D)		1. Real-time example 2. Animation 3. Real-time graphs 4. Simulations
	Symbolic-mathematical Descriptive (S-D)	1. Numerical table 2. Algebraic expression / Equation 3. Formula	
	Symbolic-mathematical Explanatory (S-E)	1. Numerical table 2. Algebraic expression / Equation 3. Formula	
	Actional-Operational (A-O)	1. Hand gestures 2. Hand demonstration	3. Role play 4. Experimental manipulations
	Material Static (M-S)	1. Concrete physical model	
	Material Dynamic (M-D)		1. Real-life example 2. Science demonstration
	Complex (C)		1. Video – real-life 2. Integrated representation

			3. Real-life Experiment
Instructional practice	Teaching approach (IP-TA)	1. Implicit / weakly directed approach to teaching with representations	2. Explicit / Strongly directed approach to teaching with representations
	Student generation of representations (IP –S)		1. Taking notes 2. Generating own representations
	Meta-cognitive strategies (IP- MC)	1. Modelling the thinking process	2. Classroom discussions 3. Reflective diaries
	Scaffolding for learning with MRs (IP-Sc)	1. Cue 2. Static linking	3. Dynamic linking 4. Model progression
	Contextual instruction (IP- CI)	1. Problems are related to the life of the students	2. Reference is made to real-life applications

The representations noted by researchers in the physics education research community over the last decade or more were considered in this study to be ‘contemporary practices’ (see Table 4.4 for the typology of instructional practices). The term traditional has been chosen to label the perspective that science is best taught by transferring knowledge from lecturer to students (Tsai, 2002). Learning science is seen as “acquiring or ‘reproducing’ knowledge from credible sources and scientific knowledge is viewed as correct answers or established truths” (Tsai, 2002, p. 773). Differentiation into traditional and contemporary practices allows one to illustrate the implementation (or not) of newer research and evidence-based practices using representations in physics instruction. For example, the practice of Lecturer 2 can be described as generally traditional when it comes to his selection of representational modes, as well as in his instructional practice.

Paper-based profiles were communicated and demonstrated to one of the participants as a pilot to gain formative feedback. Feedback included both positive aspects (e.g. “It is helpful to have the first profile as a reference for future lesson planning”) and negative aspects:

> *"If the documentation could be available electronically it would be more accessible in the long run. Participants would need training to understand the various terminology used in the representational repertoire. An explanatory key accompanying the instrument would be essential."*

This lead to a rethinking of the packaging of the message to reach the lecturers more effectively to ensure their engagement with the resources provided.

3.2.3 Second iteration of instantiation

As a result of the feedback provided in the paper-based pilot phase a second iteration of instantiation was conceptualised to design and develop a web-based presentation of three sets of resources. The first resource in the set focused on an introduction to the research and the resources by means of an overview of the study; instructions to the participants; and two documents providing the observation protocol and the theoretical framework used to develop the protocol were provided. Screen shots of the web resource are provided in Figures 4.13 and 4.14. Digital presentations in each case can be found in the CD provided with the hard copy of this thesis. A visual representation of the layers of the various pages in the web-based resources (Home; Individual and Combined profile) pages is given in Figure 4.13. The Home page and the combined pages can be seen by everyone. The individual pages (indicated with the clover sign) can only be seen by the designated participant, for example lecturer 1 can only see the set of pages customised for lecturer 1, as well as the home (labelled with a diamond) and combined pages (labelled with a diamond).

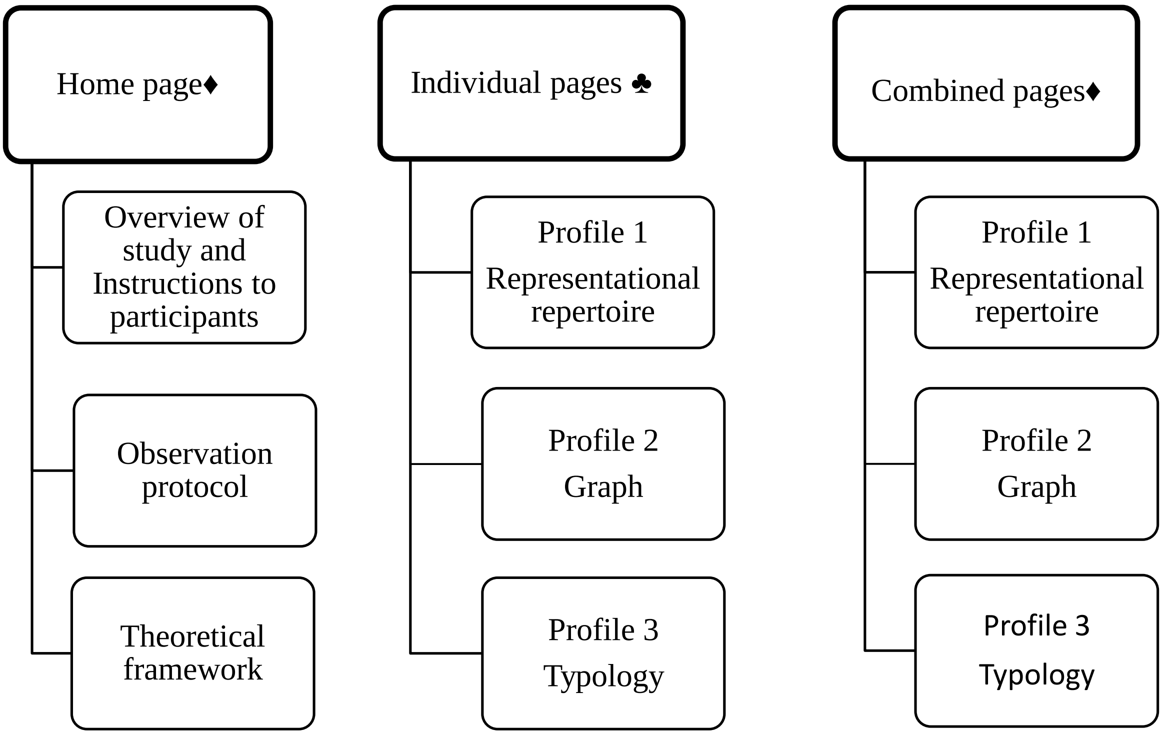


Figure 4.13: A visual representation of the layers of the various pages in the web-based resource

The first section on the home page provided and introduction to the study in the form of an overview (Figure 4.14).

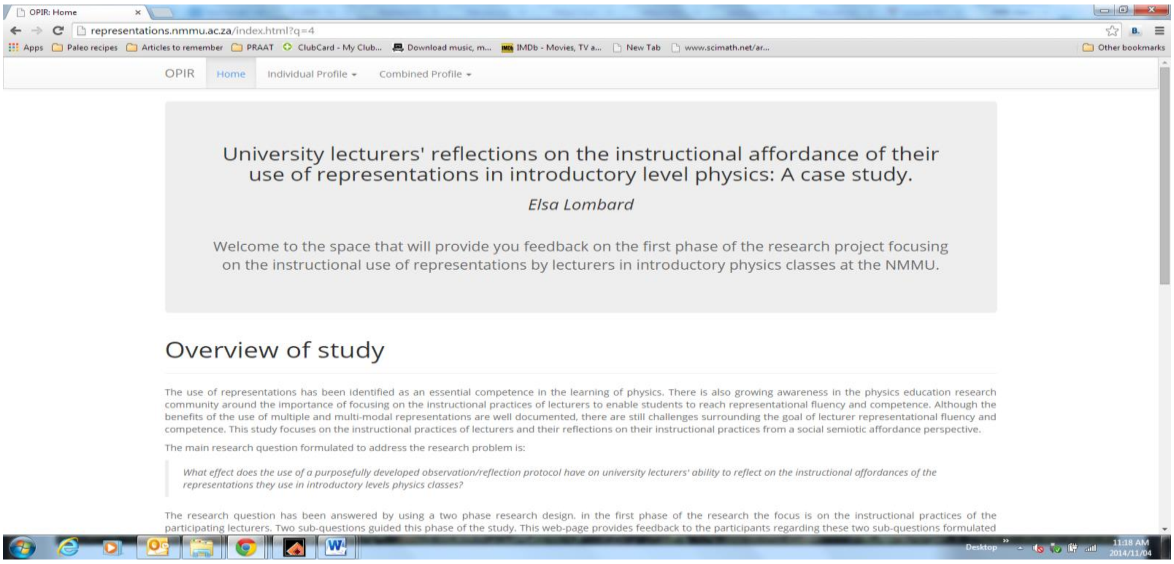


Figure 4.14: Screen shot of Home page of web-based reflection resource illustrating the first section of the introductory page

The second section on the home page provided instructions to the participants and illustrations of the observational protocol (Figure 4.15).

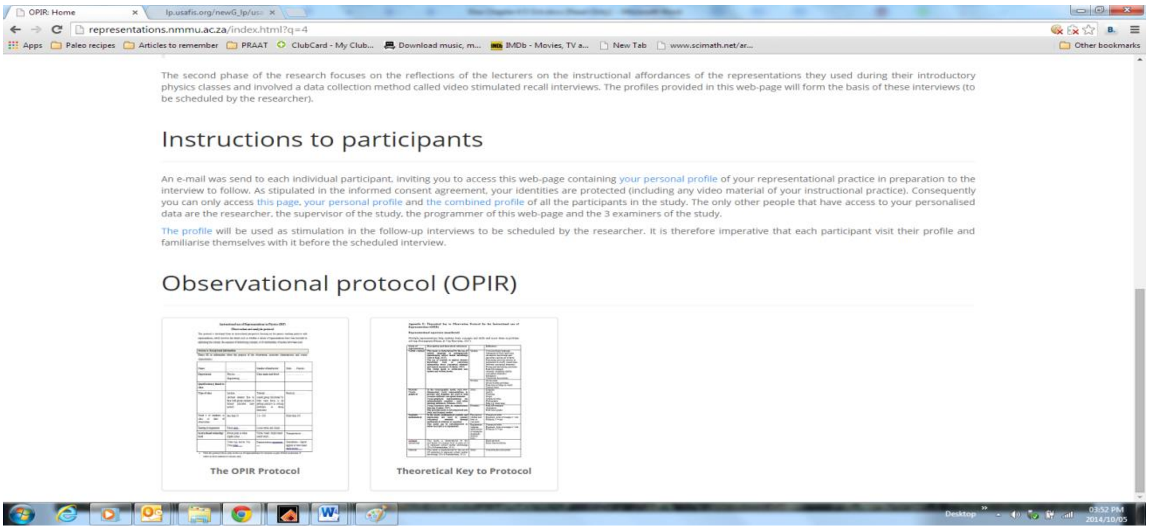


Figure 4.15: Screen shot of Home page of web-based reflection resource illustrating the second part of the introductory page with the instructions to participants and supporting documents for the observational protocol

The second set of web pages revealed the individual profiles for each of the five participating lecturers. Each participant has only access to the general introductory pages, the combined profiles of all the participants and their own profiles with the video segments as evidence of the profiles. The participants could not access each other's profiles and as such their information was confidential. In order to achieve this level of confidentiality, each participant received a personalised e-mail with their unique link to their set of personalised resources.

The individualised pages for each lecturer consisted of a summary page with thumbnails for the three different representations of their practice and the various video segments loaded as evidence of their practice. See Figure 4.16 for a screen shot of the summary page of one of the lecturers.

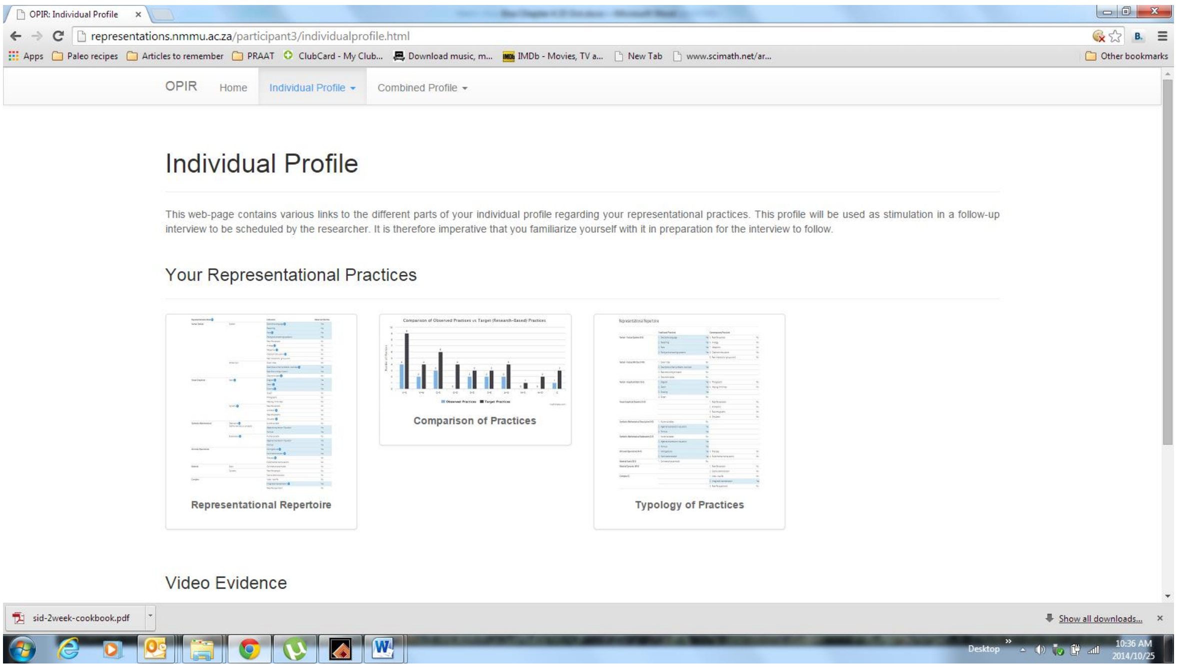


Figure 4.16: Screen shot of the summary page of one of the lecturers

The summary page of the individual profiles also contains a selection of video clips representing events where the lecturers used some of the representations contained in the various profiles (the video-clip could be activated by clicking on the desired option). The purpose of the video clips is to both serve as evidence for the various profiles, as well as to stimulate the lecturers' reflections on their instructional use of representations (which is the focus of the video stimulated reflection interviews). Figure 4.17 is a screen shot of the outline of this page for one of the lecturers.

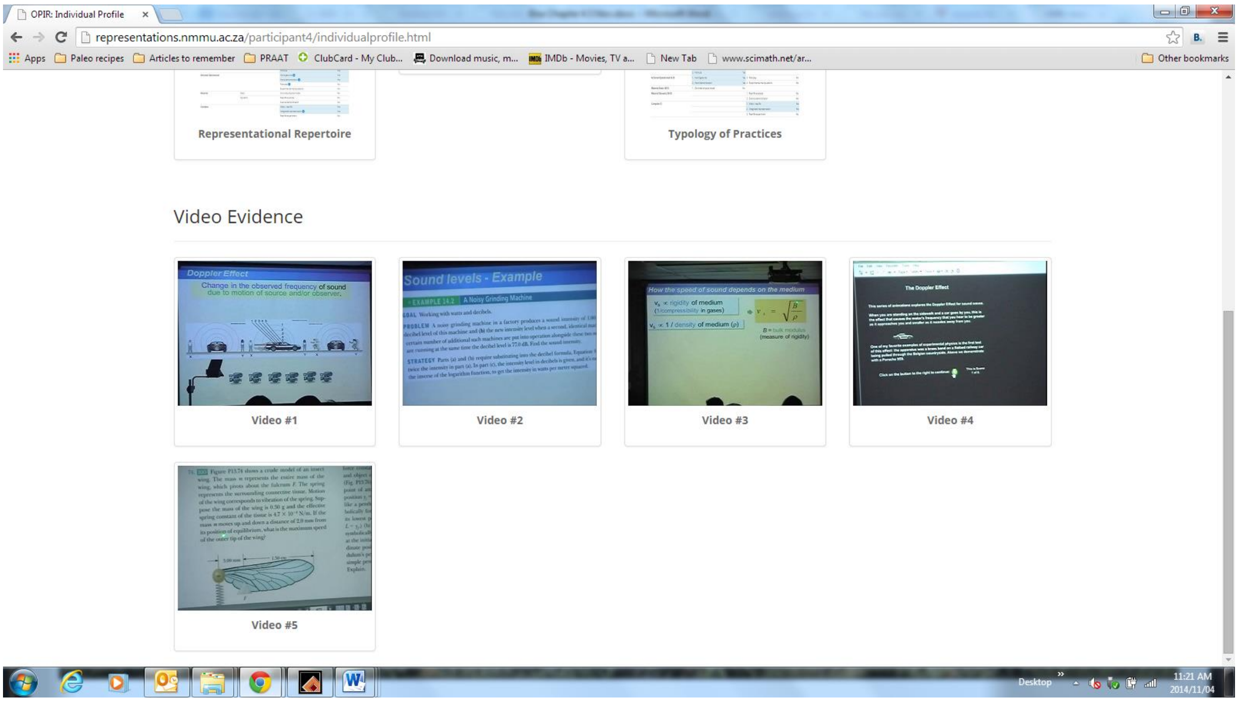


Figure 4.17: A screen shot of the web page containing the video evidence of one of the participating lecturers

The first of the three representations on the summary page focuses on the representational repertoire of the lecturer. The representational repertoire is represented in the form of a table where the representations that were used during the sample of lessons observed are highlighted. Explanations and definitions are provided for some of the concepts in the table to ensure that the interpretation of the concepts is as uniform as possible, as well as to sensitise the lecturers of the educational interpretation of some of the concepts. See, for example, the explanation provided for the concept ‘diagram’ in

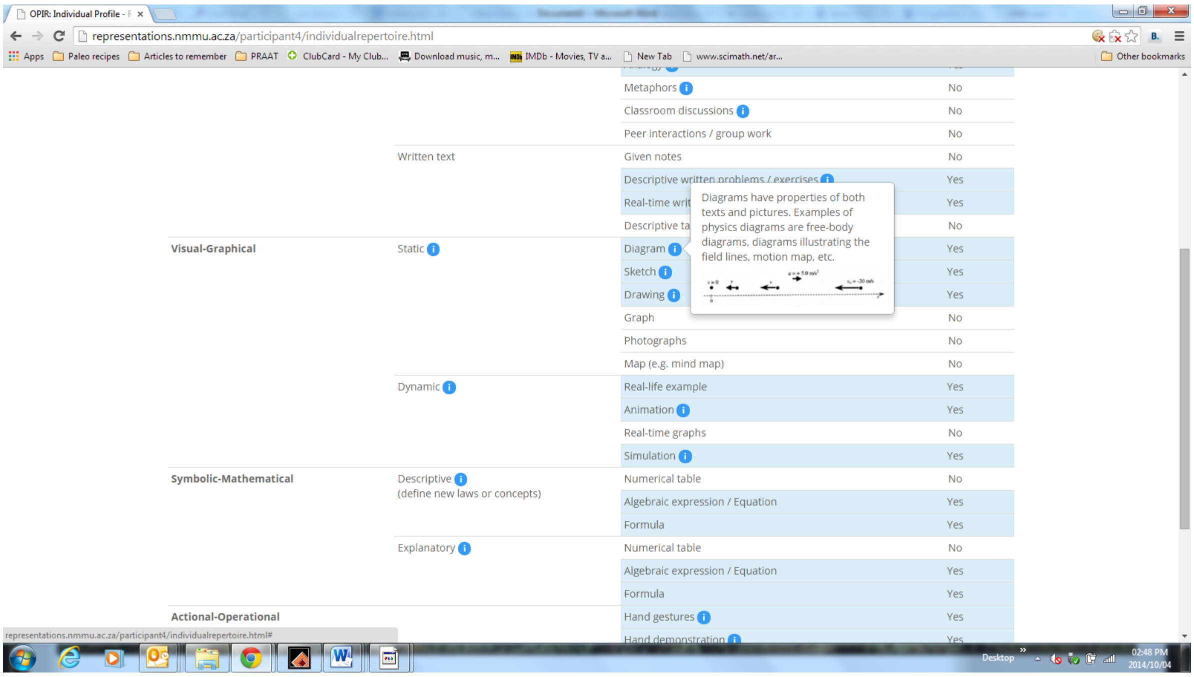


Figure 4.18.

Figure 4.18: Screen shot of the representation of the representational repertoire of Lecturer 4

The second individual representation compares the observed or manifested representations used during the selection of lessons observed with the representations identified in research as being beneficial in the teaching and learning of introductory physics (seen as the target for instructional practice in an introductory physics classroom). Figure 4.19 is a screen shot of the graph illustrating the comparison of the observed and targeted practices of Lecturer 4 as example of the second representation on the individual profile page.

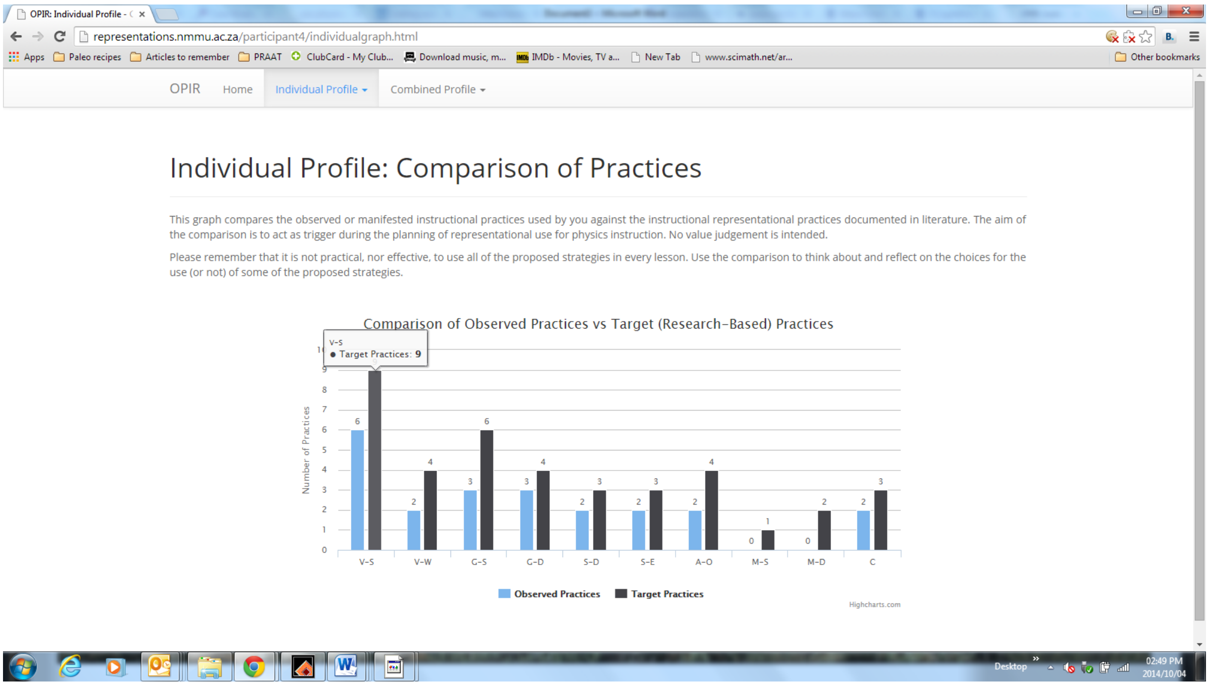


Figure 4.19: A screen shot of the graph illustrating the comparison of the observed and targeted practices of Lecturer 4

The third representation on the individual profile web pages is a table in which the representational repertoire of the particular lecturer, as well as the instructional strategies employed by the lecturer during the observational period, are classified as either representing more traditional practice or more contemporary practice. Figure 4.20 is a screen shot of this typology of practice for Lecturer 4.

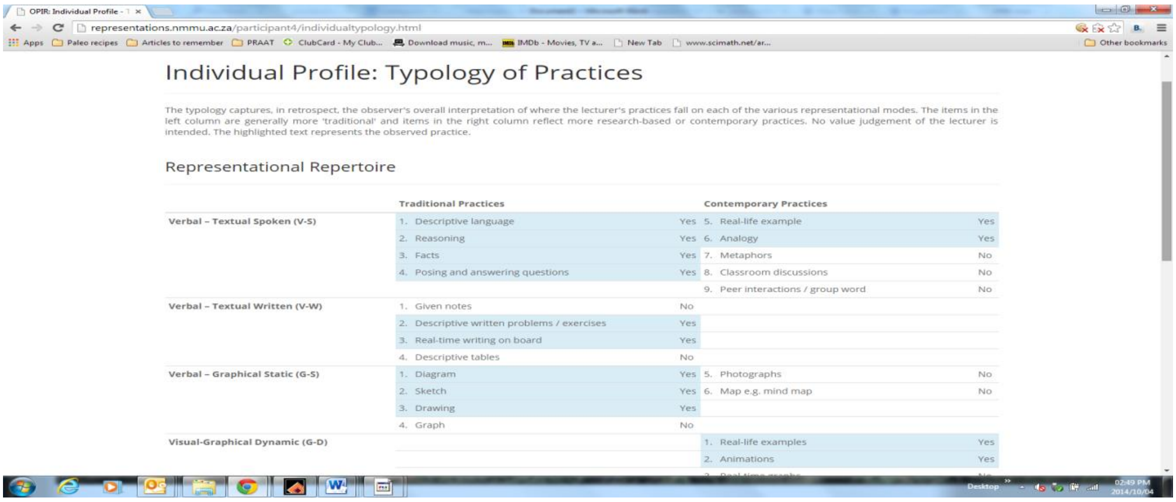


Figure 4.20: A screen shot of the typology of practice of Lecturer 4

The third set of web pages in the reflection resource contains the combined profiles of all five participating lecturers. The set of web pages has the same format as representations as the set of web pages for the individual profiles, but it contains the combined data for the five participating lecturers. Figures 4.21 – 4.24 are screen shots of the webpage with the combined profiles (the last page in the resource).

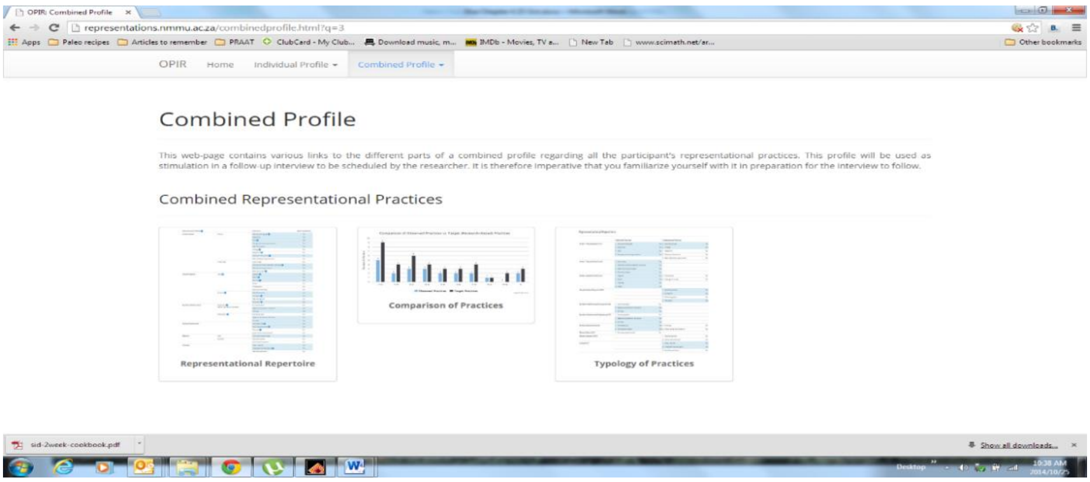


Figure 4.21: A screen shot of the first summary page of the combined profiles of the participating lecturers

The purpose of the combined profile page is to provide the lecturer with some idea of where they fit in terms of their peers.

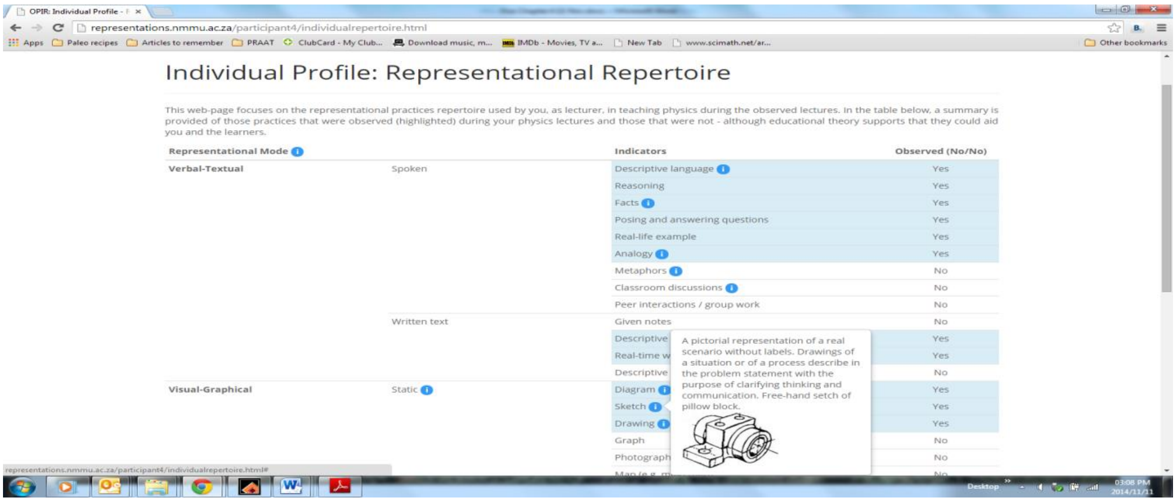


Figure 4.22: A screen shot of the combined profile of the representational repertoires when the user has clicked on an icon providing the operational definition and illustration of a particular representational mode.

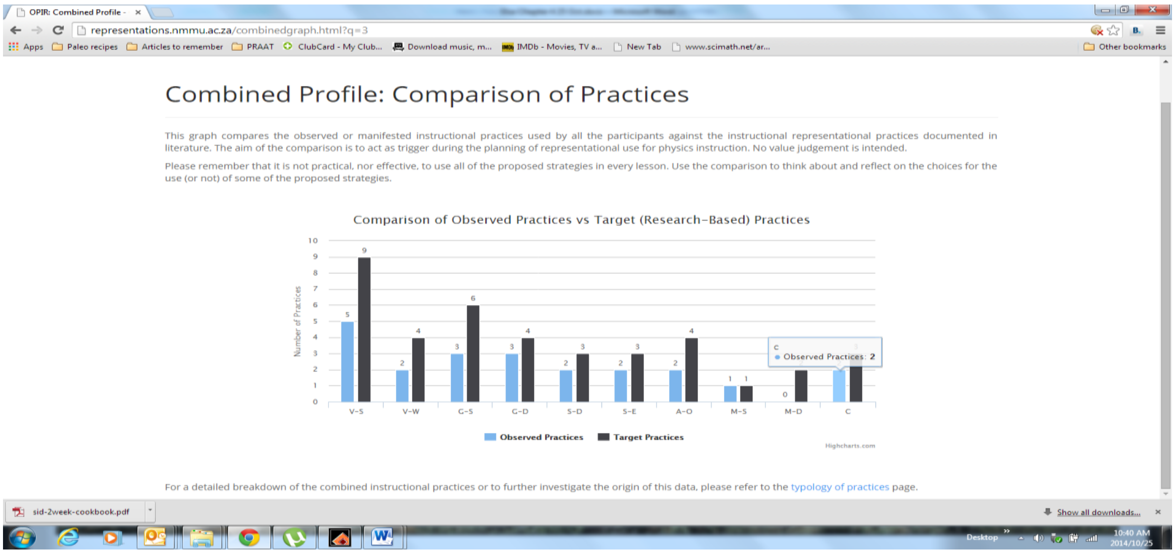


Figure 4.23: A screen shot of the combined profile for the graph comparing the participants' practices

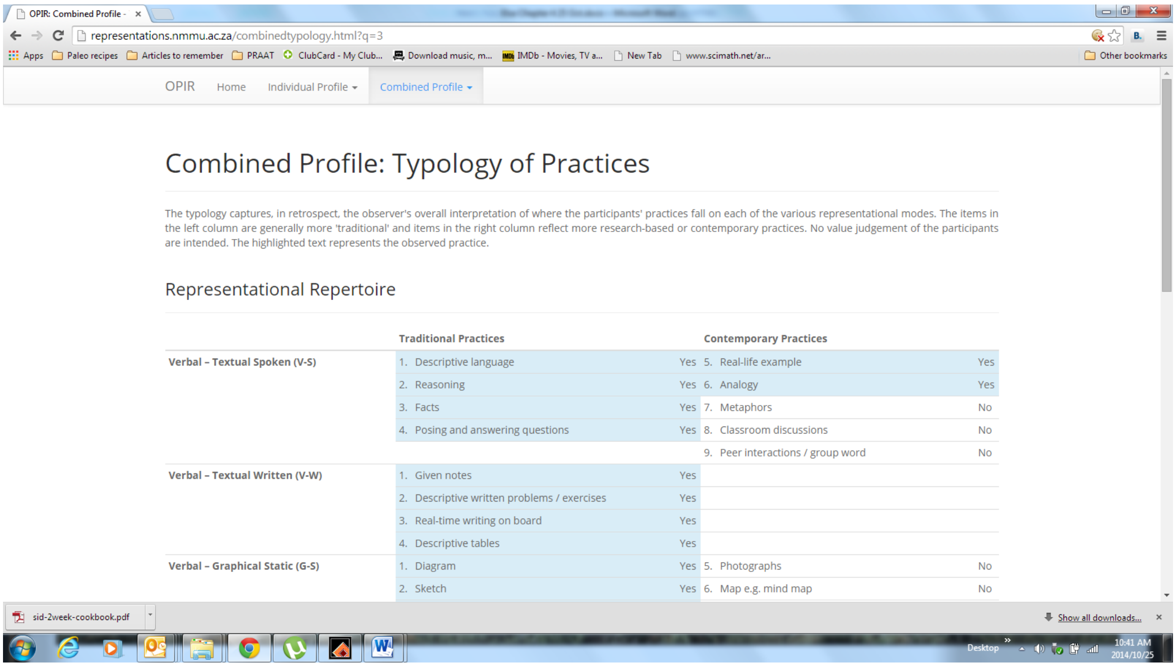


Figure 4.24: Screen shots illustrating the combined typology of the five participating lecturers

4. VALIDATION PHASE

As such, the artefact designed to address the identified research problem consists of three facets: the explanatory key, the observation protocol and the web-based set of resources representing the product of using the protocol for the analysis of video data. To determine whether the ideas, processes and communication platform implemented in the instantiation are useful, it was necessary to validate these facets of the solution. In order to do this the instantiations needed to be evaluated with respect to their effectiveness and efficiency in the performance of the given task (March & Storey, 2008). Individual face-to-face evaluator interviews were therefore conducted with the participants.

4.1 Validation of the designed artefacts

During the interviews the five participating lecturers were asked to look at the profiles generated of their instructional use of representations and asked to reflect on whether the representations were a fair and valid representation of their practice. All participants responded stating that the profiles generated and presented to them on the web-based resources were indeed a true and valid description of their practice.

> *"The profiles describe my teaching or instructional practice accurately. It is how I do this particular type of lesson. I agree with the observations as documented by the profiles."*
>
> *"The profile is accurate - I recognise myself and my teaching practice."*
>
> *"It is a true reflection of my practice and it is insightful."*
>
> *"Yes, they appear to reflect my typical lecturing style."*
>
> *"The profile makes sense".*

4.2 Evaluation of the designed artefacts

This activity in the evaluation and validation phase focused on getting feedback from the participating lecturers on the feasibility of the artefacts designed and applied to a set of video data of their instructional practice (the instantiation). The aspects focussed on include comments on the validity of the profiles in representing their instructional practice, the utility or value of the results of the instantiation, training requirements for implementation of the designed artefacts. Since some of the independent variables that may affect the success of a design in practice include the setting, the nature of the learners;

required resources and support for implementation and professional development (Collins, Joseph, & Bielaczyc, 2004), these aspects are also considered in the sections to follow.

4.3 Value of the designed artefacts

The participants were asked to indicate the value that they saw in video-taping a lesson, using the observation profile and explanatory key to analyse the video for their instructional use of representations, feeding the results in the web data base, generating the set of profiles and attempting to make meaning of the profiles. Their responses can be categorised into four categories.

Not valuable

Reluctance to change or adopt new innovations can be identified in some of the responses given (in particular with one lecturer).

> *"I am half set in my ways. I am aware of other methods and strategies available that work – or that can work. I did not try many of them. At first year level I use my default method because I feel that is the best way to go when you are confronted with large classes and students who struggles in the same class as students who could have one this on their own."*

He continued:

> *"I am not convinced that using other strategies really would make a significant difference. I am open to new things – but I am not convinced. There must be a very good reason for me to change, but I am prepared to think about this as part of an exercise."*

One of the lecturers responded with hesitation to the question on the value of the designed artefacts. He feels that the designed artefact will only be valuable if the final interpretation is done by a physicist – by implication not an educationalist, even if the educationalist has physics as part of undergraduate studies.

> *"Actually you must evaluate this in a different manner. It would be good to ask a physicist to look at [my video evidence and my profiles] to judge the quality. It may look like I know what I am talking about, and in the meantime I can talk nonsense and you would not be any wiser."*

Another perspective offered was that of linking the value of the designed artefact to its ability (or lack thereof) to measure the use of representations during instruction. While appreciating the importance of doing educational research in general, the argument is that "if it cannot be measured, it is not known". Results from classroom observations seem to be perceived as nothing more than personal opinion.

> *"I am a scientist. If I could measure something, I know something. That means – if I have measured and I have new information, then you can make interventions. If I do not know [it was not measured], then I have nothing to compare it to. Then it would be very difficult."*

Another lecturer said:

> *"The only thing is that you could be able to measure it. You must be able to say: We have done ABC and the performance of the students increased with 30%. There have to be a measurable outcome. I would be very reluctant to change things based on perception – in particular with these guys [the current students]*

> *because our pass rate vary each year with up to 10%. This is at least something I can measure myself against. I can see it."*

Physics teaching phenomena (e.g. student background knowledge, classroom settings etc.) are, however, very difficult to treat as independent or dependent variables. The perspective that non-quantitative research is not valuable since it does not measure something is not unnatural since physics lecturers began their studies in physics, mathematics and chemistry where the measurement of research outputs is the norm (Juuti & Lavonen, 2006). It has been documented that Physics lecturers appreciate results from quasi-experimental research designs because they think that they prove whether a new learning environment or new pedagogical approach is better in some way that previous ones. The criterion frequently used in the natural sciences such as physics to judge the value or applicability of interventions is with how much the new intervention improved the output of the students in the examination (Ratcliff et al., 2005).

<u>Valuable, but not for me</u>

> *"I am not here because I want to be a teacher. I do not do a conscious analysis of my teaching style. I am here because I love Physics. But it might have been a better place if we start to focus more on our teaching practice. I am telling you in all honesty – I am not an educationalist. I am also not going to promise you that I will implement these things overnight. I do not want you to have high expectations."*

Another response was:

> *"There is always value in feedback. Sometimes the feedback is such that you know that this is something you should not do; or you could implement the aspects you feel you are lacking."*

The hesitance to implement intervention was highlighted mentioned by another lecturer:

> *"I am set in my ways. I am aware of other techniques that might work. I, myself have not tried much of it. Given the circumstances of first year classes (large group and the large diversity in student preparedness and ability), I stay with my default way of teaching (as illustrated by the profiles)."*

Based on the responses from the lecturers who indicated that they would not necessarily implement the designed artefacts in their teaching practice, the following barriers or reservation were identified:

- Reservations about the extent to which participation in this type of activity can contribute to the development of lecturers' teaching practice.

> *"You need to stay away from trying to be too fancy. There are just too many fundamental things the students have a problem with. There are some resources to use – but to use these various techniques in a large class as mine and you cater for only 20% of the class is not effective for me."*

> *"I am not always approving of the modern techniques. But it is something you can work on if there is remotely some value in it. I am not convinced that using*

alternative strategies actually makes a significant difference. I am open to it, but I am not convinced."

- Perceptions of the validity, accuracy and generalizability of the outcomes of the activity.

"I do not think that it can be claimed that my teaching practice is better than somebody else's just because I have used these strategies – or not. I could have got flue that day that you observed my teaching, or I could have had a good or a bad class that day. There are too many variables."

This sentiment was reinforced by another lecturer who noted that:

"It would have been interesting if another physicist look at my profiles in terms of the accuracy and the quality of the representations used. You may document what type of representation I use, but it may be applied inaccurately – then the validity of the whole process is in danger."

- Temporal factors.

Time was given as a reason for most probably not implementing the resources designed in this study. It ranged from not having enough time to prepare incorporating or using an untraditional representational mode (such as searching for a relevant video to incorporate in a lesson) to not having enough time during the class period to implement some instructional practices due to the full curriculum.

"I would have liked it to implement a few things, but time is a problem."

"I just do not have 15 min of the time allocated to a lecture available to allow students to sort out a problem before we can move on – there is just not enough time for that."

- Characteristics of the students.

The two main aspects related to the characteristics of the students that could be identified in the responses of the lecturers are the diversity of the students in their classes, the lack or reluctance of students to participate or engage in the class; and the reluctance of students to communicate their problems to their lecturers. Some of the comments made by the lecturers are provided to illustrate these three sub-themes.

"I have a very diverse group of students in my class with diverse levels of background knowledge [based on the differences in admission criteria for the various qualifications]."

"The problem is to get the students to the point where they communicate their problems. I do not know if it is a lack of responsibility or because they are just too scared. If I know at the end of the lesson about a problem, I can address the problem in the next lecture. But because students do not communicate their problem areas, I have learned that it is best to pre-empt what the problem would be and try to address my assumption. I do not in reality know what the problem is."

"There is very little interaction with this class – and I do expect feedback and interaction from the students' side. But if there is no reaction from the student you are going to stop asking thought provoking questions because you do not get much out of them.

- Characteristics of the lecturer.

> *"I do like the availability of the extra information if you need it. Whether I am going to pay attention to that is another issue, but at least it is available."*

> *"The way I feel things should be handled in my class is the traditional perspective on teaching physics. There are certain fundamental rules that are needed to learn, but there are modern techniques you can pull in of which I do not always approve of. You are looking at the teaching of physics from a totally different perspective."*

<u>*Valuable*</u>

Some of the responses by the lecturers indicate that they found the resources valuable for a variety of reasons.

> *"I think it is very useful and insightful. I can see what I do and what I should or could do – I always like variation. I would like to implement some of the suggestions – but time is a problem."*

> *It is interesting and something that I would not have been able to do on my own. It is giving me better insight in how to approach my lectures."*

> *"I can use this as a self-evaluation tool to take stock of my teaching practice"*

- In addition to finding the designed artefact valuable in general, the following possible sub-themes were identified as in particular adding to the value of the artefact:

- Assistance with planning.

  "I can use this tool when I am planning for a lesson"

- Stimulation of reflection.

  "For a personal tool it is handy. I will help me to reflect. Normally I do not reflect regularly. I would reflect on what to do for tomorrow's class. I do not reflect on how the lesson really was."

  "I think it is insightful – you never see yourself. You do not do actual stocktaking of your teaching practice and this gives you some insight into that. I like it."

- Self-evaluation.

  "I would like to use this resource for my personal reflection and development – not as part of a formal evaluation."

- Quality of teaching practice.

  "The availability of videos about my teaching is important. I would benefit from seeing myself. I have proposed that we put videos of our teaching on the university's YouTube since I feel it will improve quality – you know your presentation will be recorded. You will then do your best. I feel it is the easiest way to determine whether you are prepared for the class or not. I am thinking of quality - internal – for yourself." and "Quality is becoming increasingly important at this university, as well as at other universities. Lecturing style is one aspect, but accuracy in terms of content is another aspect. I have a feeling the two

goes hand in hand. It would be wonderful if you can present quality content and in a sophisticated manner benefitting the student."

- Accessibility of artefact and accompanying resources for future use.

"It is easily accessible for future reference."

- Scientific nature of the resources.

"I do get feedback from the students, but they sometimes tell you what they think you want to hear. This is something done by an independent third party – measured – and this is why I like it – although there are limitations" and "It is good to get feedback from someday who knows."

Another further aspect highlighted that adds insight into the value of the designed artefact is that it provides an opportunity for the lecturer to switch roles from being the teaching to gaining some perspective from the students' side. The lecturer is placing himself in "their shoes" [the students' shoes]. This is illustrated by a comment made by one of the lecturers:

"To see myself in the video is insightful. I never get the perspective from the other side. Why is that student sitting in the front? Why does that student always prefer to sit at the back? Can they actually see what is going on in front of the class?"

The value of gaining another perspective on classroom practice has the possibility of creating multiple perspectives into the teaching and learning process and therefore may allow greater scope for the development of professional practice.

4.4 Training requirements

In order to enable the adoption and implementation the lecturers were asked to comment on whether they would need training before they could implement the designed artefacts as part of their instructional practice. The responses were given with mixed feelings. One the one hand a definite need for training or introduction into the philosophy behind the artefacts, as well as an overview of the methods to be used for implementation was expressed. On the other hand the lecturers' clearly expressed that they were averse to long, lengthy training workshops. In the light of the higher education context of the past decade in South Africa, with universities expected to do in-depth programme reviews (which went along with numerous lengthy workshops), the adverse reaction against long, tedious training sessions, can be understood.

Nevertheless, a number of positive comments were expressed:

> *"[Although the web-based resources include explanations and an introduction to the study], I do feel that you still need training. The information provided in the electronic version is helpful, but it would be better to have a face-to-face, very brief introduction to the use of the instrument and the aim behind it. The overview page and the supplementary documentation are however still needed. The personal contact would however just make the chances of it [the protocol] being used more real."*

> *"An overview of terminology used and the basic principles. Many university lecturers', whiles being experts in their field, have no formal teaching qualifications hence certain principles and terminology relating to teaching concepts is not obvious to them."*

The warning not to over-do the training is evident in the response given by this participant.

> *"I just do not want to be workshopped about this. We are not workshop people. If you send me an e-mail in which you introduce the instrument with an analysis for my use – I will like that. If I want to know something extra, I will ask. Just not a seven day workshop at the …. hotel – please."*

In terms of the format of the training more than one lecturer commented on a form of 'self-help' introduction to the programme. They link their professional identity (being a physicist) to their personal preferences and expect the training programme to cater for these preferences. Some of the comments made are:

> *"I am happy to do it [training] on my own. I function like that. I do not have a need to discuss this with somebody. If I have a problem, I might contact you to ask for clarification, but I think the instrument and supportive documentation is quite apparent."*

> *Knowing my type of personality, I would like to first try this on my own – and it seems that I will be able to do that with the support of the information that is given in terms of the descriptions and definitions of the terminology used. If I get stuck I would ask for support."*

One of the lecturers indicated that a reflective conversation would be beneficial after the first time the participants used the set of designed artefacts to initiate the lecturers to the potential and applicability of the artefacts. Thereafter they could be expected to carry on with the reflective process on their own.

4.5 Recommendations on the design of the artefacts

The responses of the lecturers included some recommendations to improve the design of the artefacts. Some of the recommendations are to include a tutorial or training session in the web-based resources where video clips are included as hyperlinks to the explanatory key to illustrate the terminology used to describe the representational repertoire and instructional practices when implemented. True to the quantitative bent of physicists and engineers another recommendation regarding the artefact design is to include some measure on how to have an indication of the efficacy of the lecturers' representational repertoire.

> *"The artefacts identify which types of representations I use predominantly and which I do not. It does not however reflect on how well I use them. I feel that if the actual quality of delivery was rated, the exercise would be more beneficial."*

While quality of delivery was not the objective of this study, evolving the designed set of artefact to accommodate both the developmental and more evaluative purposes appears to be something that could provide to be a fruitful approach for future research.

4.6 Levels of reflection

Part of the evaluation of the designed artefacts was to determine whether or not lecturers reflect on their instructional practice after they were provided with a personal profile and explanatory key as reflective trigger. Various researchers developed frameworks to assess the level of reflection reached by the participants (Bain et al., 2002; Hatton & Smith, 1995; Kember et al., 2008; see e.g. Muir & Beswick, 2007; Power et al., 2002). Although the terminology used to describe the levels vary, they fundamentally describe the degree to which reflection moves beyond mere description or technical aspects to a critical or dialectical form where practice can be reconstructed (Muir & Beswick, 2007).

Design of analytic tool to assess levels of reflection

As part of the grounding phase of the design-based study, aspects of the frameworks reported on in research literature relevant to the context of this study were combined with the philosophy behind the SOLO taxonomy of Biggs and Collis (1982) with the aim to assess the depth of lecturers' reflective thought they achieved. The combination of some elements of the various published frameworks and the levels described in the SOLO taxonomy resulted in the development of the Level of Reflective Practice taxonomy (see Table 2.1 in section 3.7). On the first application of the taxonomy to assess the interview data, I realised the initial taxonomy as represented in Table 2.1 was conceptually too dense for use by subject lecturers without significant training in the assessment of reflection. It was therefore deemed necessary to develop a more simplified version of the taxonomy and, as a result, the 'Expected Outcome of Reflection' (EOR) taxonomy was designed and developed (see Table 4.5). The EOR taxonomy, which operationalizes the outcomes expected from reflection by lecturers on their instructional practices, is grounded in theory on reflective practice and assessment. Since the EOR taxonomy is a result of the application of the analytic framework developed during the grounding phase (the Levels of Reflection taxonomy represented in Table 2.1) it is considered a further artefact of the research project.

The EOR taxonomy was then used to assess the levels of achievement by the lecturers as evident from their video-stimulated reflection interviews. Coding the reflections of the lecturers happened at a whole (overall) VSR interview level and not at any one section within the interview level. This means the whole interview was examined to code the highest level of reflection according to the EOR taxonomy (Kember et al., 2008).

Results of applying the EOR taxonomy

The sections and sub-sections which follow report the findings of this analysis. It is, however, important to remember that the focus of the current research project is to establish the potential of the artefacts designed and developed to address the problem of promoting reflection by physics lecturers on the instructional affordance of their use of representations in their introductory physics classes. As such the focus of the analysis was on establishing the "artefact's utility, quality and efficiency" (Hevner et al., 2004, p. 85) and not on the actual levels of reflection displayed by the lecturers as such.

The reflections of the lecturers recorded during the video-stimulated reflection interviews were transcribed and coded using the EOR taxonomy (Table 4.5). The results of this analysis were recorded in a table that would enable the researcher to determine the highest level of reflection achieved by the individual lecturers, supported by representative quotations (Tables 4.6 to 4.10). The instructional affordance of the representational use in physics classes was operationalised as the answer to the question: "what constraints and possibilities for making meaning are offered by my use of representations as part of my instruction?"

Table 4.5: Expected Outcome of Reflection (EOR) taxonomy

Type of Reflection	Level	Expected Outcome of Reflection
Reconstructing	E	
The understanding developed through reasoning as described in level 4 is used to reframe or reconstruct future practice or professional understanding. Asks 'what is the relevance of the problem itself?	Level 3	Develop new understanding based on a "knowing-from-within" integrated into lecturer's personal philosophy or theory of teaching asking: "What does it mean to be a physics lecturer in the social, cultural and political context I find myself in?
	Level 2	The reflective response leads to a conclusion or plan of action based on reasoned understanding of incident or issue.
	Level 1	The reflective response also considers the reasons for, possible implications of, the conclusion or plan.
Reasoning	D	
The reflective responses highlight in detail significant factors underlying the event or issue and show why they are important to an understanding of the incident or issue.	Level 3	The discussion evident at level 2 incorporates insights from a different perspective (e.g. different learning, student or theoretical perspective).
	Level 2	Discussion of the factors underlying the event or issue; considers or compares possible alternative explanations or, and/or considers the reasons for, or possible implications of the conclusion.
	Level 1	Relevant facts underlying the event or issue analysed in detail is.
Relating	C	
Reflective responses relate or make a connection between the event or issue and the lecturers' own skills, experience, learning, or understanding.	Level 3	The rationale or discussion on the connections includes an insight or understanding arising from the connections made. Asking 'How do I know if it works/if I am effective?
	Level 2	The response includes a rationale for or limited discussion of the connections identified in level 1.
	Level 1	The event or issue is related to the lecturer's own strengths, weaknesses and personal learning, or to professional matters (pedagogy, curriculum, assessment), or to future practice.
Responding	B	
Lecturer responds to the event or issue by making observations, expressing feelings, or asking questions such as What should I do, know, or find out?	Level 3	As for level 2 and in addition the response identifies a problem or poses a question about teaching.
	Level 2	As for level 1, by the response also includes a judgement regarding the issue or event.
	Level 1	The response includes expressions of personal feelings in relation to the issue or the event.
Reporting	A	
The reflective responses report what happened or what the issue or event involves. Non-reflective description of experience.	Level 2	Broad description including significant details. Some evidence of thoughtful action.
	Level 1	Minimal technical description.

Lecturer 1

Based on the analysis of Lecturer 1's reflective responses during the video stimulated reflection interview, the highest level of reflection achieved by Lecturer 1 can be labelled as falling in the Relating category at level 3 (see Table 4.6).

Table 4.6: Level of reflection achieved by Lecturer 1

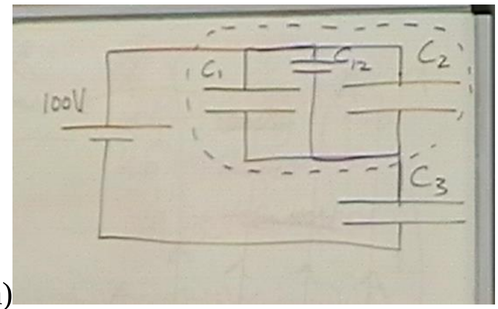
Type of reflection	Level	Representative quotation
Reconstruction (E)		-
Reasoning (D)		-
	C3	"… my board space is very limited, which forced me to rather use a combined representation. Doing it like that overcomplicated the problem to the students. They would have done better if I kept the circuit diagrams clean and separate - even if I did indicate it with a different colour."
Relating (C)	C2	"I wanted to simplify the process of analysing and calculating various values for capacitance … I realised that I should rather draw individual diagrams instead of using a complex diagram."
	C1	"There are also other representations that could be used to enhance the students' understanding. E.g. building the actual circuit diagram on a bread board to illustrate the circuit diagrams."
Responding (B)	B2	"I could most probably divide them in groups and let them solve the problems, asking some of them to do the solutions on the board. But with the lack of engagement that they show in a 'normal' class I just do not feel it would be worth my while to try something like that."
	B1	"Students are very reluctant to engage in classroom activities. It effectively becomes a one way street where I talk ... and they are reduced to copying answers from the board. I would ask questions to specific students … they would just not answer"
Reporting (A)		-

The reflective response from Lecturer 1 contains a detailed description of the instructional event. He also reflected on a factor that impedes the effectiveness of the learning (and teaching) in his module, namely students' lack of engagement in the classroom activities. As the lecturer reflected:

> *I keep on reminding them to ask questions and that I will gladly help them – they can come to my office afterwards if they are too shy to talk in class. Very few of them come to my office. But in class you would not get any reaction from them. Eventually you will just carry on because the syllabus still needs to be covered. This lack of engagement is a general complaint with the rest of the staff that teaches these students. One of [my colleagues] made the comment the other day: "They were dead again today. No reaction from them. They just sit there."*

To illustrate the allocation of a C3 rating for his reflection, the following evidence can be presented. Evidence was found pointing towards the realisation by the lectures that a perceived affordance offered by the use of an integrated representation (superimposing the equivalent capacitor C_{12} onto the original circuit diagram, to represent the replacement of the two original capacitors (C_1 an C_2) in series with a new equivalent capacitor) (see Figure 4.25a and 4.25b) instead of individual diagrams to represent equivalent capacitance, might in fact hinder learning instead of helping the students.

After viewing the video clip the lecturer commented that the use of the integrated representation (the superimposed circuit diagram) was not such a good idea and he should change his teaching approach in future lessons.

(a)


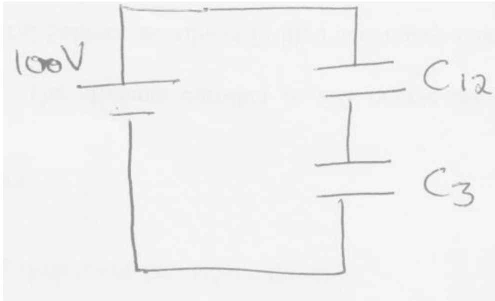
(b)


Figure 4.25: A screen shot of the integrated representation (a) used by Lecturer 1 instead of drawing the equivalent circuit diagram (b)

> *I would normally draw individual circuit diagrams for each of the steps in determining the total equivalent capacitance (Figure 4.25b), but my board space is very limited, which forced me to rather use a combined representation (Figure 4.25a). Doing it like that overcomplicated the problem to the students. They would have done better if I kept the circuit diagrams clean and separate - even if I did make use of a different colour. I wanted to simplify the process of analysing and calculating various values for capacitance, potential difference and charges on the individual and the circuit in total. I realised that I should rather draw individual diagrams instead of using a complex diagram.*

Lecturer 2

Lecturer 2's reflective responses during the video stimulated reflection interview, resulted in the highest level of reflection achieved by to be labelled as falling in the Reasoning category at level 3 (see Table 4.7). There is no evidence of reflections that could be categorised as Reporting, Responding or Reconstruction.

Table 4.7: Level of reflection achieved by Lecturer 2

Type of reflection	Level	Representative quotation
Reconstruction		-
Reasoning	D3	"The subject I teach falls under the engineering department - it has a different philosophy than pure physics. Engineering is a skills-based domain and not a content domain. Learning thus happens by solving problems and doing exercises. I am only the facilitator providing them with the basic concepts. The focus is thus on concept development through solving problems."
Relating	C2	"I have decided to not use prepared Power Point slides any more. Only when I want to show a visual illustration. When you use the PPt slides, you tend to go too fast through the explanation of the problems."
	C1	"I would deliberately not complete all the aspects of a problem to force them to have to go back to the problem and try the rest of it themselves."
Responding		-
Reporting		-

The lecturer (a physicist) reflected on the nature of Engineering and how it differs from the knowledge structure of physics. He recalled how he had to adapt his pedagogy to accommodate the difference in knowledge structure. He explained that Engineering is seen as an applied study domain and as such the emphasis is on the solving of problems and not necessarily on the physics concepts by itself that are embedded in the problems.

Lecturer 3

Based on the analysis of Lecturer 3's reflective responses during the video stimulated reflection interview, the highest level of reflection achieved by the lecturer can be labelled as falling in the Relating category at level 2 (see Table 4.8). There is no evidence of reflections that could be categorised as Reporting, Reasoning or Reconstruction.

Table 4.8: Level of reflection achieved by Lecturer 3

Type of reflection	Level	Representative quotation
Reconstruction		-
Reasoning		-
Relating	C2	"My experience of this class is there is little interaction. You expect feedback from the students. I do not know how to get that sorted out. You could do this by asking thought provoking questions – but if there is no reaction from the student's side, you start to lose courage. You feel you do not get much back from the students."
	C1	"For the first year students this is my default methods because I feel the students get maximum benefit out of it given the circumstances: large class and the fact that I have students who can follow on their own and other students who experience problems."
Responding	B2	"I am set in my ways; this is how I feel it should be done [instructional practice] – but it is a traditional perspective; … there are modern techniques that can be used but I do not approve of it. My brain does not work like that."
Reporting		-

Evidence of introspection (where personal meanings are given to events that happened in the class) and non-reflective description of the experience can be found in the interview (coded B2). Evidence of reflecting on a personal level can be found in the numerous statements used during the interview where the lecturer indicates that he is not convinced that these more contemporary instructional approached to teaching with representations in introductory physics classes are making a difference in the pass rate of his students.

The identification of problems experienced with his instruction (e.g. the diversity of students; unresponsiveness of the students during class; lack of communication by students about their problems; a need for quality teaching in physics classes), were coded as C2 since the problems were related to professional matters (his pedagogy and the curriculum), as well as to his future practice (even though he claims not to be willing to change his future practice). See the representative comment for category C1 in Table 4.8 for the relation and the comment representing C2 to illustrate the inclusion of a rationale for his response in C1.

The lecturer focuses strongly on the quantitative evidence needed to address any potential educational or pedagogical facts identified as barriers to students learning (including comments such as "*If I have measured and I have new information [proving the effectiveness of the new approach], then I can do an intervention*") and justifying his traditional approach to teaching introductory physics using arguments based on his perception of the success of this approach in the past (but offers no evidence of its actual success in the past – anecdotal or empirical) and on the student characteristics (large class, diverse students, and unresponsive students) he identified.

Lecturer 4

Lecturer 4's reflective responses during the video stimulated reflection interview, resulted in a ranking in the Relating category at level 2 (see Table 4.9). There is no evidence of reflections that could be categorised as Reporting or Reconstruction. The allocation of a C2 level of reflection as done on the basis of the evidence described below. It cannot be represented by a neat quotation and as such as description is provided in Table 4.9, instead of a representative quotation. Based on the challenges the lecturer identified (lack of engagement by students in both in-class and out-of-class academic activities; variation in students' mathematical and physics pre-knowledge; time-constraints in terms of contact-time scheduled for the module), the lecturer reflected on how he did and could adapt his instructional practice to address these challenges. Some of the adaptations include for example, moving around in the class is while using a laser pointer with Power Point slides, allowing him time to communicate with the students on a more face-to-face basis; inviting students to ask questions in class about tutorial exercises given as homework; structuring his PowerPoint slides to keep the 'packaging' of the information standard; using animations, real-life videos and dynamically linked simulations were possible to encourage engagement and link to the students prior knowledge.

Table 4.9: Level of reflection achieved by Lecturer 4

Type of reflection	Level	Representative quotation
Reconstruction		-
Reasoning		-
Relating	C2	In his reflections the lecturer identified problems he experiences in his classroom, related it to his own strengths and that of his students, his pedagogy and the curriculum, and could engage in a rationale for the problems and the solutions he identified.

	C1	"I would have for example loved to spend more time on solving problems during instruction time; I would have loved to invite a student to the board and ask him or her to work through the problem with me in real time. But there is just not enough time. "
Responding	B2	"If you do not even try the exercises at home, then you waste your time when the exercises are discussed during a tutorial session. The students seem to rather prefer to act like sponges and think if they sit in the class they would by some miracle absorb the knowledge."
Reporting		-

Lecturer 5

Lecturer 5's highest level of reflection achieved can be labelled as falling in the Reasoning category on level 1 (Table 4.10). There is no evidence of reflections that could be categorised as Reporting, Responding or Reconstruction.

Table 4.10: Level of reflection achieved by Lecturer 5

Type of reflection	Level	Representative quotation
Reconstruction		-
Reasoning	D1	"The representations attempt to instil a methodical, precise mind-set for solving typical physics problems. They are based on consistent and disciplined notation and methods and are conveyed primarily by displaying a logical progression of reasoning and drawings. A degree of repetition is employed to promote the concept simplicity and precision as the preferred means of tacking complex analytical problems."
Relating	C1	"I break up lengthy analytical problems into 'bite sized' pieces in such a way that each piece appears simple to the learners."
Responding		-
Reporting		-

The lecturer provided a detailed rationale for the instructional approach used in the class, revealing insight and understanding of the connections between the choice of representational mode, the instructional strategy employed and the underlying nature of the discipline content.

4.7 Overview of reflection

The above results of the individual levels of reflection obtained by analysing the video stimulated reflection interview data by applying the designed EOR taxonomy were collated in a composite table (Table 4.11). The table reveals diversity in terms of reflective categories and levels, illustrating the levels of reflection achieved by the lecturers.

Table 4.11: Overview of levels of reflection attained by lecturers

		Reflection category													
Participant		Reporting A		Responding B			Relating C			Reasoning D			Reconstructing E		
Name	Gender	A1	A2	B1	B2	B3	C1	C 2	C3	D1	D2	D3	E1	E2	E3
Lecturer 1	M			x	x		x	x	x						
Lecturer 2	M						x	x				x			
Lecturer 3	M				x		x	x							
Lecturer 4	M				x		x				x				
Lecturer 5	M						x			x					

4.8 Cross-case reflection themes

The lecturers' reflections during the video stimulated interview were analysed to determine the various aspects they reflected upon and the type of discourse they used during these reflections. A cross-case analysis revealed the following factors as constraining factors that influence their choices regarding their instructional use of representations:

- time needed for lesson preparation
- students' background knowledge
- students general culture of learning
- students' engagement in classes
- students diversity in classes in terms of preparedness
- nature of disciplinary curriculum
- the disciplinary identity of the lecturer.

In many reflections the lecturers identified the amount of prescribed content as limiting their possibilities for carrying these teaching strategies because they feel that there is no time for experimenting with a variety of teaching strategies, not getting it right and then having to repeating content. They reason that it takes too much time to try something new: both in preparation and in time lost in class when it does not work as represented by this statement:

> *"We do not have time to repeat things. I would have loved to spend more time doing examples with them – going through the problems step by step. I go through*

the examples a bit too fast. But again it is a matter of time. I talk and I know that I have lost some of them. But I do not have 15 minutes spared to slowly go through each example. There is just not enough time."

The lack of time was the biggest obstacle that inhibited the lecturers' efforts to move away from a more traditional teaching approach. They had pursuable ideas in mind, for example how to incorporate more visual material in their classes, or incorporate the students more in the solving of the problems, but at the end it all came back to the effort it takes to successfully and effectively incorporate these ideas in their classes, and they just do not feel they have the time and the mental energy to pursue their ideas.

These factors are meaningful in terms of reflections, as they indicate the ways in which the lecturers explain to themselves the barriers to their instructional practice. The factors identified above can be categorised to reflect both external factors (lesson preparation, student factors, and the physics curriculum) and internal factors (their disciplinary identity) influencing their instructional practice. Three following main discourses were identified as being present in the lecturers' reflections, namely student deficit discourse, disciplinary discourse and personal discourse.

Student deficit discourse

All five the lecturers commented on what they perceived as the unpreparedness of the students' as a collective for the demands expected of university learning. The forms of unpreparedness varied from the lack of background knowledge in physics, but also in the supporting disciplines such as mathematics, the lack of engagement during class rime, the unresponsiveness of the students when invited to ask and answer questions, the lack of commitment to work outside the class period and the general lack of interest in the subject.

The provision of support to struggling students by means of adapting the teaching approaches was not considered as a viable option by most of the lecturers. As one lecturer explained:

> *"You must in fact stay away from trying to be fancy. There are just too many fundamental things they have a problem with. There are some means of support. But to use various techniques in a large group like this [just under 150 students] to satisfy the needs of twenty percent of the class is not always effective for me. That is how I feel."*

The same lecturer commented on the low pass rate (being less than 50%) of the physics courses in general. This reveals an internal conflict. On the one hand the lecturers are worried about the low pass rate, the unpreparedness of the students and that the students do not achieve the outcomes the lecturers desire; but on the other hand they seem to only look away from themselves in their search for an answer to their problem, instead of focusing the light on their own practice and what they are able to do.

Although the lecturers described the same 'problems' with the students, their reactions to these problems were varied. The great diversity lectures experience in their classrooms is part of a South African reality. This reality forces lecturers to make pedagogical choices (Quinn, 2012). They may choose to focus on what worked in the past and carry on with that. They may also choose to keep on doing what they are doing because they feel satisfied that they are ‘doing OK’ and do not feel embarrassed by their teaching [after viewing of their video recording of their teaching]. One lecturer chose not to work with a data projector to deliberately slow the tempo of the class in order to allow the students to follow the modelling of the problem solving in ‘real-time’.

One of the lecturers had interesting alternative ideas of what he could do with the students, but he noted that because they do not engage in his class he has lost any motivation to try something new and chose to disengage emotionally from the class. Another choice encountered during the interviews was to deliberately disrupt the traditional and expected type and flow of teaching and learning activities by only solving parts of a problem (leaving the rest to the students to solve), or to solve the problem conceptually, leaving the actual computations of the solutions to the students.

The picture painted by the participating lecturers resonates with what is reported in literature. In a recent study by Linder, Airey, Mayaba, and Webb (2014) the argument was put forward that what might appear as a lack of work-ethic from students, may in fact be the symptom of a lack or representational competence. They conclude that it is the physics department’s responsibility “to ensure that students develop sufficient representational competence during their undergraduate studies” (Linder et al., 2014, p. 248).

Disciplinary discourse

The lecturers used the disciplinary discourse to reflect on the nature of physics knowledge and the impact that had on their instructional practice. The use of the disciplinary discourse in reflection is illustrated by the statement:

> *"People [physicists] do not really reflect on our [teaching] practice because they focus on the development of their subject through research rather than on teaching".*

Interestingly the lecturer reflected in the third person, personally distancing himself from the statement. The statement almost became a description of a general observation he is making, reflecting on the nature of the community he belongs to. A contradictory viewpoint was offered by another lecturer, also reflecting on his disciplinary identity in relation to his teaching responsibilities.

> *"I am not here because I want to be a teacher. I do not consciously analyse my instructional practices. I am here because I love physics. ... Maybe it would have been a better place if we would pay a bit more attention to the pedagogical aspect as well."*

Personal discourse

The overwhelming feeling expressed by the lecturers was that they have little time, energy and commitment to devote to teaching. The students' lack of engagement and response in the classes lowered their motivation to try some alternative representational modes or instructional strategies, although they may have pursuable ideas of what they could to.

> *"Getting demonstration equipment to and from the class is a mission. There is nobody to help you and with only 10 min in-between classes there is no time to*

clean up. The class is also overcrowded making it difficult to store equipment to clean up later. In the end you just abandon the idea."

These data indicate that the use of the designed profiles and the supporting video material did stimulate reflection, but there still seems to be many are unsolved aspects – such as how the lecturers can be assisted to look for their solutions within themselves and their practices.

5. CHAPTER SUMMARY

This chapter reported the results and findings of the design process, as well as the findings of the assessment of the level of reflection by the lecturers when presented with the results of the designed artefacts to stimulate reflection on the instructional affordances of the representations used in the observed introductory physics classes. The validation of the results of the instantiation of the designed artefacts was positive. All of the lecturers validated the profiles as accurate and valid. During the evaluation of the artefact the responses were varied. The response strategies varied from not valuable, to valuable but not for me, to valuable. Various barriers to the implementation of the designed set of artefacts were identified, while the possible areas of application were similarly extracted from the data. Finally the lecturers' level of reflection was assessed using the specifically designed Expected Outcome of Reflection taxonomy (Table 4.6) to code the transcribed video stimulated reflection interviews of the lecturers.

In the light of the aim of this study, namely to establish proof-of-concept of an artefact (or set of artefacts) designed to promote physics lecturers' reflection on the instructional affordance of their use of representations at in their introductory physics classes, the results of the study seem positive to have achieved this aim. The implications of the research findings reported in this chapter will be discussed in the next chapter.

CHAPTER FIVE

REFLECTIONS ON THE DESIGN PRODUCT AND PROCESS

1. INTRODUCTION

Design theorists (Archer, 1995; Dilnot, 1998) agree that practice alone does not constitute research. Reflection on the work must take place in order for design knowledge to be considered as research. The final phase in the design-based research process is consequently reflections on both the outputs of the research and on the design-based research process followed using a set of guidelines such as those proposed by Hevner et al. (2004). This chapter serves as an overview of these reflections.

The study set out to design and develop an intervention as a solution to the complex problem of promoting reflection by lecturers on their instructional practice and to advance our knowledge about the characteristics of these interventions and the processes used to design and develop them. The theoretical outputs of the study, namely an abstract design methodology, a design framework consisting of design guidelines, along with the design principles of the study, are discussed in the first section of the chapter. The second section of the chapter uses the seven criteria proposed by Hevner et al., (2004), namely problem relevance, research rigour, design as a search process, design as an artefact, design evaluation, and consideration of the research contributions and communication of the research, to evaluate the quality of the design process followed.

2. REFLECTIONS ON THE DESIGN PROCESS

The first question to reflect on is: How are the findings of this study legitimised as research? Plomp (2007) argues that the design of an intervention becomes design research by systematic reflection. He notes that the challenge for design-based research is to "capture and make explicit the implicit decisions associated with a design process, and to transform them into guidelines for addressing educational problems." (Plomp, 2007, p. 17). Edelson (2002) concurs and characterised the design process as entailing a sequence of decisions that the researcher has to make to balance goals and constraints at any point in the design process. These decisions can be described as decisions around design procedure (specifying the processes), problem analysis (characterising the goals, the context and the problem), and design solutions. Edelson (2002) further relates these sets of decisions to a corresponding useful and generalisable theory, namely design methodologies, design frameworks and domain theories (as mentioned in Chapter 3 section 3). The links between the design choices made and the corresponding theories are given in Table 5.1.

When reflecting on the outputs of the design-based study, what matters are the lessons learned (the design choices as illustrated in general on the right hand side of Table 5.1) during the design process. Capturing the lessons learned as theories is a way of making them available to a wider audience (Plomp, 2007).

Table 5.1: The relationship between the design choices made and the type of theory it may lead to (after Edelson, 2006)

Type of theory	Design choices made in study (lessons learned)
Design methodologies (prescriptive in nature)	A general design procedure providing "procedural design principles" guidelines for the process and development of the design
Design frameworks (prescriptive in nature)	Design solution that communicates decisions about the design itself (Edelson, 2006). It provides a set of "design guidelines for a particular class of design challenge" (Edelson, 2002, p. 114) or the characteristics an artefact must have to achieve a particular set of goals in a particular context.
Domain theories context theory outcome theory (descriptive in nature)	Domain theories are linked to decisions made during the problem analysis stage of the study e.g. assessment of design context (Edelson, 2006). Context theory describes challenges and opportunities presented by a class of contexts, while outcome theory describes a set of outcomes associated with the intervention.

The three main knowledge claims relevant to this design study are: the development of a design methodology, the formulation of design guidelines (the design framework) and the formulation of contextual and outcome principles. The knowledge claims are intertwined in one another, for example one of the domain theories (context theory) was deducted when the problem analysis that formed part of the general design methodology was undertaken. As the methodology followed in the study forms the anchor to the abstraction of the design guidelines (design framework) and the design principles (domain 'theory'), the design methodology used in the study will be discussed first in the sections to follow. This section is followed by a discussion of the design guidelines and the design principles. Although these knowledge claims appear to occur in a linear fashion, their development did not always happen in this way and, as such, the reflections below sometimes contain aspects of each.

3. THE DESIGN METHODOLOGY USED

By its nature, design-based research aims to develop research-based solutions for complex problems in educational practice. This aim resulted in a research process that is a "systematic study of designing, developing and evaluating educational interventions (such as materials, products and methods) as solutions" for these complex problems with the aim to advance "our knowledge about the characteristics of these interventions and the processes of designing and developing them" (Plomp, 2007, p. 13).

The theory describing the design methodology is a general procedure consisting of "procedural design principles" (Van den Akker, 1999) followed during the design process and the development of the intervention (Edelson, 2006). In the execution of this design study, the research approach proposed by Herrington et al. (2007, p. 4093) was adopted with states that "[t]he proposed solution to the nominated educational problem is developed from consideration of relevant literature, consultation and collaboration with researchers and practitioners, and as an instantiation of the principles derived from these sources.". This approach resulted in two "design modalities or research sequences" (Jorno & Gundersen, 2014, p. 7): one sequence for the design of the artefact and the second sequence for the instantiation of the artefact.

The general research framework proposed by (Hevner et al., 2004) served as guide for reflecting on the first research sequence. Figure 5.1 illustrates the general research framework used as guide during the design process. The knowledge base depicted on the right hand side of the framework (the theories used to inform the design, called 'kernel theories', as well as the methodology used to design and develop the intervention) provided "the raw materials from and through which [the] research is accomplished" (Hevner et al., 2004, p. 80). Incorporating the theoretical foundations in the design of the intervention ensured rigour in the design process. Three types of kernel theories were incorporated in this particular design: semiotic affordance theory acted as the orienting framework, reflection on action acted as the framework for action, and representations in the teaching and learning of physics was the chosen domain-specific theory (diSessa & Cobb, 2004).

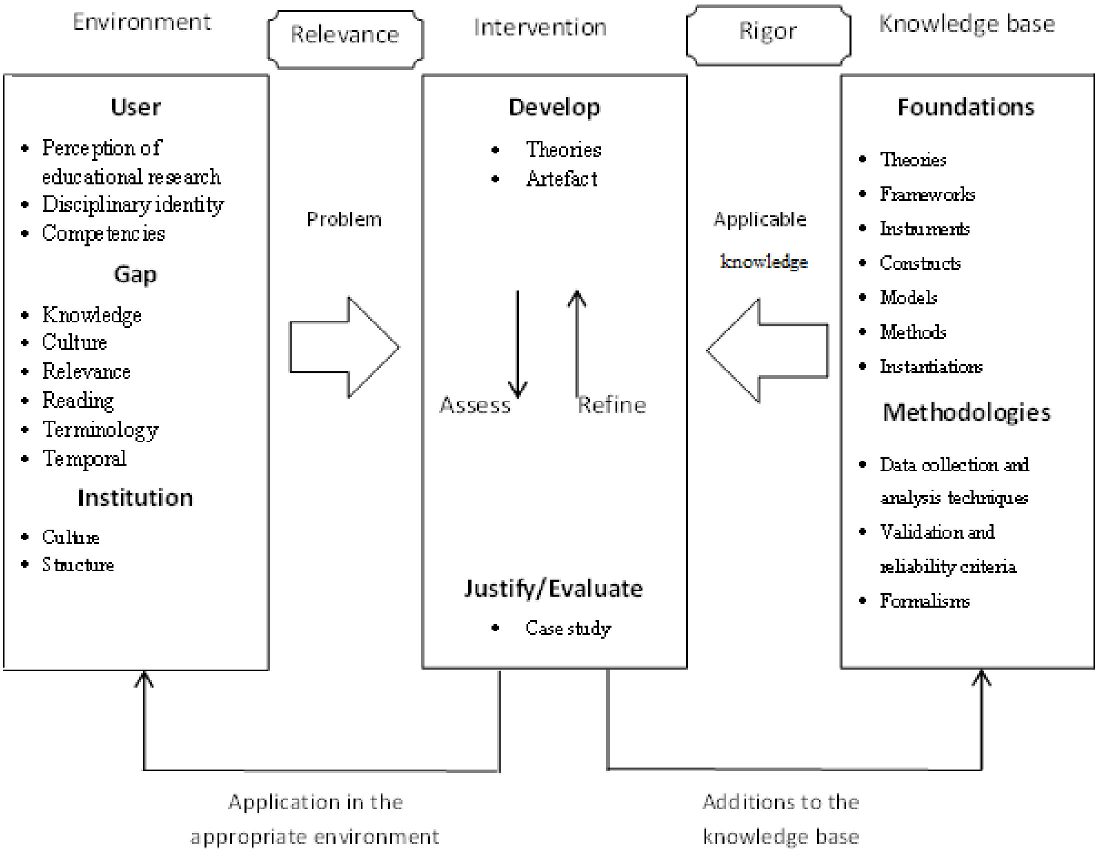


Figure 5.1: Research framework used for this study (adapted from Hevner et al., 2004; Herrington et al., 2007)

The methodological knowledge based foundations (right hand side of Figure 5.1) of the intervention consisted of guidelines provided by well-established research methodologies for implementation during the justification and evaluation phase of the study. The environment defined the problem space in which the artefact exists (Simon, 1996, cited in Hevner, et al., 2004). For this study the environment is framed around the user (the introductory physics lecturer) in a higher education institution. Based on the view held by Hevner et al. (2004), where a problem is seen as a gap between the goal and the current state, the users of the artefact can be thought of as having a particular gap profile or areas where they could do with support. In the problem space the goals, problems and opportunities that define the research problem can be identified or found. The problem space is shaped by the disciplinary identity of the participants who find themselves in the problem space. Taking all of the challenges, possibilities and constraints of the environment into account assisted me to define the ‘problem’ as I perceived it to be. Framing the research activities to address contextualised problems helped maximise the relevance of the research.

The iterative nature of the designed intervention is illustrated by the middle column in Figure 5.1. This design-based research study was conceptualised as building and evaluating an artefact designed to meet the identified research problem, the goal being utility (Hevner et al., 2004). Weaknesses in the design of the intervention were identified by moving through various assessment cycles after which the design was refined and reassessed.

3.1 Reflecting on the problem analysis stage of the research process

The driving force behind the design of the intervention was the analysis and contextualisation of the research problem. The aim of the problem analysis stage of the research was to understand the problem and entailed investigating the problem in published research, the contexts in which the artefact would be implemented, the potential users of the artefacts and any existing solutions or tools that might have been suitable to contribute to a solution to the problem. The problem analysis was conceptualised around three aspects of design-based research, namely: (i) the importance of clarifying the intended user's world and needs and the objectives for an artefact to be designed (theoretical problem analysis) (Juuti & Lavonen, 2006); (ii) the iterate design of the artefact, and (iii) ensuring the practicality or "the user-friendliness of research findings" (Van Velzen, 2013) of the artefacts (as part of the intervention) by paying attention to solving a problem grounded in the context of the problem domain.

The context for which the intervention is designed is fundamental to both the process and the product (Hoadley, 2004) as it determines the ecological validity of the designed intervention (Barab & Squire, 2004). Understanding the context in which the design will be implemented also improves the relevance of the research findings as well as shaping the desirability, practicality and effectiveness of designs (Van Velzen, 2013). These notions can be fairly easily understood theoretically, but in practice understanding the natural context of the intervention proved to be more complex since "the boundaries of context and what constitutes naturalistic … prove[d] to be elusive" (Barab & Squire, 2004, p. 11). The social and cultural contexts of the intervention were conceptualised in terms of "characterising situations as opposed to controlling variables" as "… design-based research focuses on understanding the messiness of real-world practice, with context being a core part of the story and not an extraneous variable to be trivialized" (Barab & Squire, 2004, p. 3).

3.2 Reflecting on the naturalistic context of the intervention

The questions that confronted me during the grounding phase of the design study were: Who am I designing the intervention for? Is it designed for an individual or do I design it for the academic department or for the university? What constraints are present in the larger context that might shape the local context of the intervention and limit the relevance of the resultant theory? To ignore, or not take cognisance of, the broader institutional context in which the intervention is situated constitute a fundamentally flawed design study (Barab & Squire, 2004). Adhering to the advice given by Barab and Squire (2004), the seams between these boundaries were examined as part of the design work, adding to the ecological and consequential validity of the intervention. The conception of the designed intervention consequently took into account the constraints of the real-world context or the setting (a South African university) in which the contexts of implementation for this study (introductory physics classes) are nested.

Organisational fit is crucial to the successful development and implementation of a designed artefact (Hevner, et al., 2004). The world of higher education teaching is a socio-material world and the classrooms, the length of periods, the grouping together of students in various courses are materialisations of a specific way of doing and embody a specific institutional (or social) code or script (Rip, 2009). This material order structures the practice for lecturers and its societal embedding: social relations between lecturers and students, between the physics lecturers and the various staff members and the university as a whole, and the university and the broader societal environment such as the professional bodies of the various disciplines. In such a socio-material order, physical and institutional boundaries are created and maintained that enable some developments and constrain others. Similar to many classrooms all over the world, introductory physics at the higher education institution where the intervention was implemented is taught in large lecture classes (2-4 hours/week), with tutorials included in the lecture time and laboratory sessions (2-3 hours/week) scheduled separately from the lecturers (Redish & Steinberg, 1999). Lectures were mostly presented as expositions by the lecturer, with little or no student participation focusing mostly on the modelling of the solution of sample problems.

The socio-material context provided by situating the study in a higher education institution influenced the design of the intervention through the recognition that these variables would be constant and very real constraints for the duration of the study. It is not to say that they may not change in future iterations (for example, the number of periods allocated to a module may change, or the professional body for a particular qualification may decide that their students may not be grouped with other students, etc.), but for the duration of the study the assumption was that the intervention would not be in a position to change the social relations between the various role players or alter the physical and institutional boundaries of the institution.

3.3 Characterising the variables

In line with empirical evidence cited in research literature, the findings of the design study revealed a substantial influence of contextual variables in shaping the "desirability, practicality and effectiveness" (Dede, 2005, p. 6) of the intervention. For example, the challenges to offer tailor-made professional development and perceptions around the inherent worth of educational research influenced the conditions for success associated with the designed intervention. Resolving the challenges associated with a multitude of contextual variables is not easy task and I had to make choices around features of the designed intervention to address as many of the possible variables to ensure the desirability, practicality and effectiveness of the intervention. Based on responses during the initial iteration (pilot phase) of the study, one such choice was to expand both the training guide and produce a web-based resource. Another choice was to communicate the results of the lecturers' use of representations in the form of graphs, numbers and tables instead of heuristics to encourage a numbers-based physics community to engage with their own instructional practice.

The notion of dependent and independent variables can be used to provide a distinction between outcomes that should be considered in a design-based research project and those variables that may affect the outcomes of the project (Collins et al., 2004). The dependent variable for the study entailed the level of reflection achieved by the participating lecturers at the end of the intervention. The independent variables that may affect the success of the design in practice fall into three categories: design variables; user variables; and environmental or context variables (see Table 5.2).

Table 5.2: The independent variables that may have an effect the intervention

Variable	Description of variable
Design variables	Interaction between researchers and users Dissemination effort Communication by researchers – implementation pathway The use of technical language
User variables	Awareness of research Disciplinary identity Attitude towards educational research Subliminal resistance towards change Pedagogical knowledge and skills
Environmental variables	Issues of research (e.g. relevance) Poor interaction between disciplines Expectations of the disciplines Incompatible ways of knowing Institutional setting (large classes; broad content coverage expectations; classroom infrastructure; time-table scheduling; poor student preparation or motivation). Required resources and support for implementation Professional development

As the objective of the intervention was to design and investigate the potential of an intervention to narrow the documented gap between current research-based knowledge and lecturers practice a contextual variable of importance in this study was the nature of the gap that exists between the lecturers perceptions and the idealised or aimed for state in terms of reflection on the use of representations when teaching physics. The researcher knowledge used in this study include findings from two disciplines, namely physics education researchers who specialise in the learning and teaching aspect of physics (Henderson & Dancy, 2008), and academic staff professional development practitioners specialising in development of academic staff's professional role of teaching their discipline. While working towards the same goal of enhanced instructional practice in physics classes, a gap not only exists between the knowledge fields of these two disciplines but also between what physics lecturers believe they know about teaching their discipline. The general nature of the types of gaps that need to be considered in terms of artefact design (which are presented in Table 5.3) formed part of the conceptualisation of the design of this particular intervention.

As noted earlier, the artefacts developed were grounded in research literature spanning both the domains of physics education (instructional use of representations in introductory physics classes) and educational research (reflection and the professional learning or development of lecturers). Understandings distilled from the literature resulted in an awareness of the knowledge gaps, cultural gaps and temporal gaps that needed to be addressed by the intervention. Research findings also pointed to the problem of terminology gaps, and an attempt was made to address this issue through the development of an operational key that supplemented the observation protocol in both the paper and web-based artefacts.

Table 5.3: Nature of gaps that needed consideration in terms of the artefact design

Gap	Description
Knowledge gap	More effective communication between the groups would ensure all to be more informed
Culture gap	Researchers and lecturers fail to understand each other, gain knowledge from difference process and communicate only within their own peer group.
Relevance gap	The groups value investigation of different types of problems

Reading gap	The different groups do not read each other's literature
Terminology gap	Each group uses terminology that is not understood by the other. This is particularly true of researchers
Temporal gap	Lecturers do not have the time to read or do research on their teaching

3.4 The implication of disciplinary context on the design of the intervention

Disciplines are described as communities whose knowledge practices are embedded within distinct socio-cultural contexts (del Favero (2003), cited in Harvey, 2011). The cultural context in which this intervention is rooted is that of the prevailing culture of physics and engineering departments in many universities, both nationally and internationally. As such, the implications of the disciplinary context for the design of the intervention were made explicit, considered and addressed in the final design of the product (artefacts).

Potential for tension due to different ways of knowing

Firstly there are implication resulting from the potential for tension between the researcher (from the physics education tribe with a staff development agenda) and the lecturers (physics experts who emphasise knowledge aspects of their discipline) (Neumann et al., 2002). The pure hard knowledge structure (physics) and applied hard knowledge structure (engineering) disciplines were required to implement an applied soft knowledge structure (educational) intervention. This difference potentially creates a mismatch in ways of knowing – even when the intervention contains a 'theory-embedded tool' (Kinchin, 2009). The applied soft knowledge nature of physics education research, where researchers have incomplete control of all the input variables, is unfamiliar to pure physics researchers who are used to carefully controlled studies (Fraser et al., 2014). The fact that educational research results are sometimes dismissed as being irrelevant because of a lack of control over variables and certainty in answers was evident in the comments made by lecturers in this study, for example:

> *"I am a scientist. For me is to know, to measure. So – if I have measured and I have new information – then I can make interventions. If I do not know – there is nothing to compare. That is the issue. But it is something you can work at – if it has by any chance has any merit. I am not convinced that to use another technique would actually make a big difference. I am open to it; but I am not convinced. You have to be able to measure it. You must be able to say that you did ABC and the students' achievement has improved with 30%. There must be a measurable outcome."*

The epistemological nature of physics as discipline influenced the communication style of the resources developed. For example:

- the format of the profiles representing their instructional use of representations incorporated displays in the form of tables and graphs, instead of a heuristic,
- the theoretical references providing the justification for the inclusion of a representational mode or an instructional strategy in the observational protocol was included in the web-based resource to address the sentiment verbalised by one of the lecturers "I attach value to evidence revealed by research", and

- including the video-evidence in the web-based resource to allow the lecturers to 'see for themselves' where the results displayed in the tables and the graphs contained in their profiles come from (i.e. the source of the data).

The strategy of the communication was to strive to provide authentic evidence as justification for choices made and conclusions research with the aim of moving closer towards convincing them of the worth of 'non-measured' evidence and to entice them into reflecting on their instructional practice. The physics lecturers' natural inclination for control over variable and quantitative evidence posed a particular challenge to the study and it highlighted the need for sustained engagement with the lecturers if the intervention was to influence their perceptions of inherent differences between hard and soft knowledge structure disciplines and their worth. As this study is the first leg of this journey, it would be only possible to report on the influence of focusing on this variable in the future. The awareness of the disciplinary identity of the lecturers was however a constant companion during the conversations and interactions with the lecturers.

Potential tension due to differences in expectations

Henderson and Dancy (2008) pointed out the different expectations about how physics education research and other non-physics education research lecturers should work together to improve physics learning. Non- physics education researchers might expect conversations and engaged responses, while physics education researchers, according to Henderson & Dancy (2008), might expect unengaged implementation of interventions. It was evident from the feedback received from the sample of participating lecturers that they preferred not to have discussions and mutual engagement with the staff development practitioner, as evident by a representative statement by one of the participating lecturers:

> *"Just do not workshop me. Send me the information and I will figure this out by myself. If I then need some assistance, I can always call upon you".*

> *"I am happy to do this on my own. I function like that. I do not have a need to engage in a conversation with somebody. If I experience a problem, I may [engage in a conversation]."*

As such I adapted the preliminary design sequence based on the feedback received from the lecturers. Instead of including reflective conversations with the participating lecturers as proposed by literature as good practice in engaging lecturers in reflective practice, I designed the 'conversation' to happen on paper in the form of a training guide included in the reference manual (Appendix B), minimising the face-to-face interaction between the physics education researcher and the physics lecturers.

Expectations of the nature and structure of professional development

Professional development of various kinds is often needed for a design to be successful (e.g. workshops, design meetings, videos of exemplary practice of the design, guided practice with expert practitioners, reflective meeting with colleagues, and so forth). Respondents throughout the project acknowledged the need for professional development, but proffered the caveat that the training must be conscious of time-constraints and over-training. They stated that they would feel more comfortable with mainly self-directed training. However research advises that professional development practitioners need to challenge lecturers' core beliefs (their basic assumptions about teaching) if their classroom practice is to develop (Kinchin, 2002). As such, the responses of the physics lecturers posed a particular challenge to the professional development aspect of the development process.

The sentiment of the lecturers around professional development is a variable that was identified during the reflective interview following the instantiation of the designed artefacts and as such it was not addressed during the design process or during the instantiation phase. It was however incorporated in the study in the following two ways. Firstly the lecturers' expectations were incorporated in one of the design guidelines (see section 4) formulated for fellow researchers to take note of when designing an intervention in a similar context. In the second place the expectation lead to the inclusion of a training guide in the final reference manual of the intervention (Appendix B) enabling lecturers participating in future iterations of the intervention to interact with the resources on their own. This strategy however will have to be empirically verified as useful in future iterations of the intervention and might change depending on the findings.

Resistance to change

During the interviews and interactions with the lecturers, evidence was found of subliminal resistance to interventions or expectations which implicitly request equal attention or a greater focus on the teaching and learning than on of physics' knowledge. This resistance is illustrated by a comment made during an interview: "You do not really reflect on your [instructional] practice because you focus on the development of your subject through research instead of on teaching". The lecturers see themselves as passive recipients of knowledge, citing many reasons why they cannot be proactive (it is taking too much time; the students do not engage; the curriculum is too full; the students are too diverse to really achieve some success) and appeared unwilling to take charge of their own learning about their teaching. The expression that "someone must measure my instructional practice [performance] and tell me whether it is effective or not" has the implication that someone else controls the knowledge around instructional practice relevant to each individual topic in undergraduate physics.

One way of addressing this resistance is to establish ownership of the change. However, a change in attitude does not happen overnight and as such it is probable that this variable will only be truly addressed through sustained and intense interaction between physics lecturers and physics education researchers. What did become evident during the course of the study was a gradual change in attitude towards a willingness to engage with the ideas put forward in the study and to consider the incorporation of some representational modes in future. The sentiment expressed in the statement "I am willing to do this as an exercise", gradually changed to reflect a sentiment "as a personal tool, this is very handy. It will help me to reflect". The design guideline formulated in section 3.6 addresses this variable.

Doubting the inherent worth of educational research

A comment made by one of the participant lecturers illustrates this issue appropriately.

> *"You have to actually stay away from being too fancy. There are just too many fundamental things that are problematic for the students. There are some resources. But, to use these various techniques in a large group to fulfil twenty percent of the class's needs is not always effective. So this is how I feel."*

This would appear to be an indication of the "worth" (an indication of the extrinsic quality of the phenomenon that are contextually influenced) of educational interventions – seeing it as "being too fancy". The challenge was to get the message across that paying careful attention to the type of representations used during instruction, and how these representations can be used to help both the twenty percent of students in need of additional support and the eighty percent of the class that on the surface seem to be grasping the content. Solid authentic evidence in the form of references to published research were provided to substantiate the propositions made through the items included in the observation protocol, the definitions or examples of the key concepts, as well as in the various other resources provided in the reference manual and the web-pages. The potential for success of this strategy will only be verified or falsified through future iterations of the intervention.

A further strategy employed to address the perceived worthiness of educational research was to provide the lecturers with evidence of their own strengths; areas indicated by literature as being ‘good practice’ that they already use. The results of their own profiles were structured in such a way that the representational modes they already use were clearly displayed and not communicated as a deficit in their practice, but rather as something good that is already part of what they do.

3.5 Second design modality (research sequence) describing the instantiation

The second phase of the study involved the instantiation of the designed artefact. The design sequence followed for this phase is illustrated in Figure 5.4. One of the design challenges addressed in this sequence was balancing the back-and-forth movement between empirical work and theoretical work.

The primary data collection strategy chosen was systematic classroom observation because it allowed me to collect data of actual behaviour and not stated or perceived behaviour. With the purpose of retrospective access in mind, video recordings were made of the lecturers' teaching. The video data was analysed using the designed observation protocol for the instructional use of representations (OPIR) in physics with its accompanying key of operational definitions for the key concepts incorporated in the protocol.

The results of the analyses of the video data were interpreted and initially displayed in a paper based format. Based on feedback received from a lecturer a set of web-pages were developed containing profiles of the lectures' representational repertoire, a comparison of their current practice against the aimed for instructional practice as deducted from empirical evidence, and a classification of their practice as either predominantly traditional or more contemporary in terms of their instructional use of representations. These profiles, plus video segments were designed to serve as evidence of lecturer's instructional practice and as evidence-based triggers for reflections on their instructional practice during a video-stimulated reflection interview. Video-stimulated recall has been shown to be an effective research tool to elicit lecturers' knowledge in action as it provides the specific contextual complexity of professional knowledge essential for professional growth to occur (Reitano, 2005). The levels of reflection achieved during these interviews (the goal of the study) were evaluated using a newly designed instrument called the Expected Outcome of Reflection (EOR) taxonomy.

The second modality or research sequence described above is illustrated pictorially in Figure 5.2. The diagram emphasises the dual levels of 'work' the design methodology has to do, namely (i) the empirical work of collecting the relevant data, selecting the most suitable techniques to analyse and represent the findings that enable the achievement of the goal of the study, and the reflections by introductory physics lecturers on their instructional practice intertwined with (ii) the theoretical grounding of the designed instruments, the methods used to implement the instruments and the sense-making of the findings of the empirical work. These modalities were undertaken to help ensure that the design-based research project was executed with the necessary rigour and logic required to enable the research question and sub-questions to be answered.

4. DESIGN FRAMEWORK

The second main output of this study is the design framework. The design framework is the "design solution" that provides a set of "design guidelines for a particular class of design challenges" (Edelson, 2002, p. 114) and includes decisions about the design itself (Edelson, 2006). A framework consequently consists of a collection of coherent design guidelines.

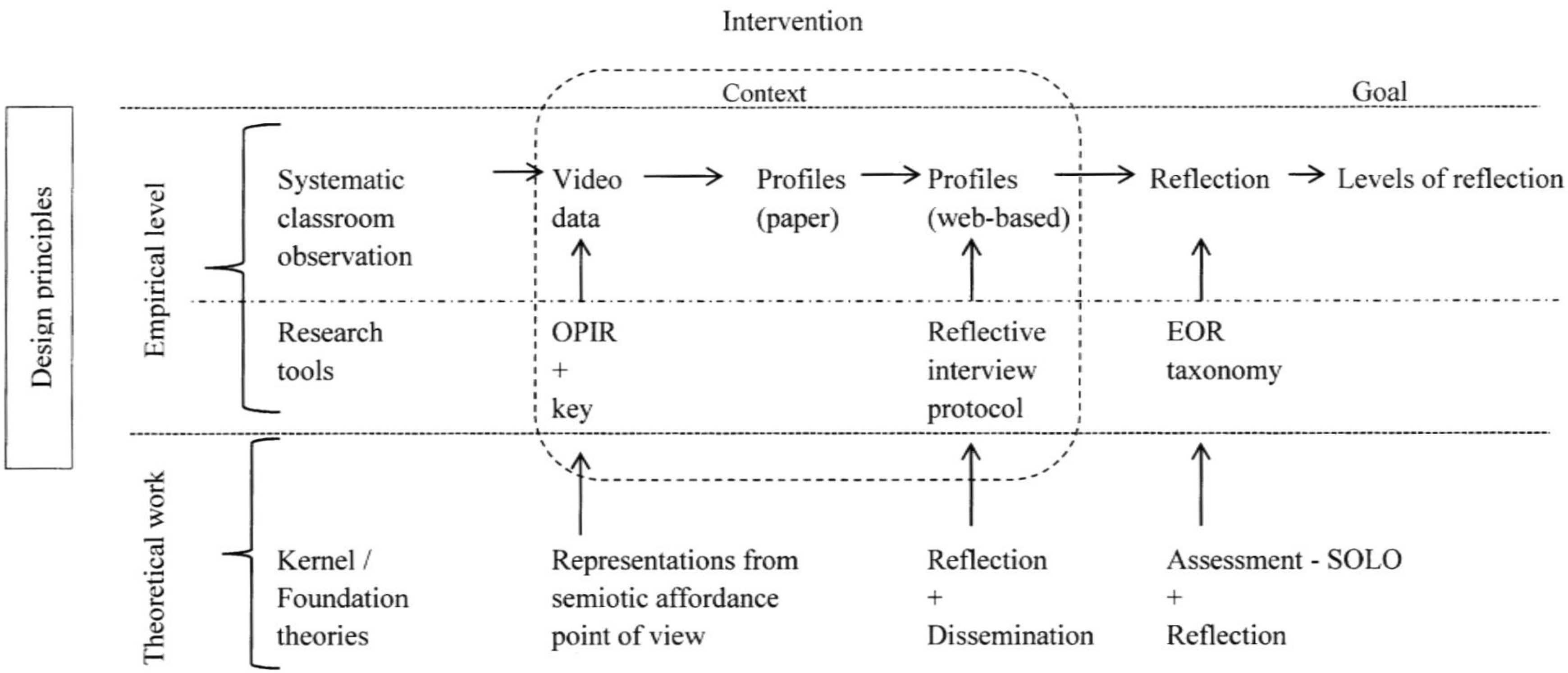


Figure 5.2: Design sequence or modality employed in the instantiation of the artefacts

Upon reflection on the problem analysis phase of the study, the implication of the context variables on the design of the intervention, and the research sequences designed to ensure a rigorous and logical research approach that would generate answers to the research question and sub-questions, a set of design guidelines were abstracted. The design guidelines can be understood as design knowledge and are a common way of reporting results from design-based research (Van den Akker, 1999). van den Akker's definition of a design guideline suggests the inclusion of the context, where the specific guideline is applicable, an emphasis on what to do and how to do it and arguments for why it should be done. He uses the term intervention for "products, programs, procedures, scenarios, processes, and the like" (Van den Akker, 1999, p. 5).

Guideline 1: Know the disciplinary identity of the potential users

> *If you want to design an intervention to promote reflection by physics lecturers on their instructional practice, then you are best advised to conceptualise that intervention around the disciplinary identity of the potential user because the epistemological structure of a discipline influences the pedagogical practices and believes of the lecturers.*

This design guideline was motivated by the interaction with the lecturers who participated in the study. Reflective interactions revealed that they do not believe that they have the necessary experience with educational research methods, and nor do they have the time to fully converse with relevant literature and the body of physics education knowledge (Sharma & McShane, 2008). Most such lecturers are committed, in the first place, to managing a demanding physics research programme, which requires time, effort and resources. As such, an accessible framework that allows them to proceed knowingly and efficiently – and in a scholarly manner – should be invaluable and provide a useful and practical framework to support scholarly inquiry into their teaching. Reflections by some of the lecturers also suggest that solid and sufficient evidence of theoretical grounding in the features of the artefact would narrow the potential tension based on the diversity in epistemology that may exists between them and science education and professional development researchers.

Guideline 2: Aim at establishing a sustained and intense interaction between researcher and users

> *If you want to design an intervention to promote reflection by physics lecturers on their instructional practice, then you are best advised to establish a sustained and intense interaction between you and the users of the intervention because it will increase the likelihood of an intervention to be utilised and it will alleviate some of the potential tensions that may exist between the research and the users of the intervention.*

Again, this design guideline was motivated by the feedback received during the interviews. While the problem analysis activity in the grounding phase went some way in addressing the problem of the latent apprehensiveness and potential tensions identified as influencing factors to the design and implementation of such an intervention, and recognition that establishing such a sustained and intense interaction would be a demanding activity that takes time (Van Velzen, 2012), more in depth initial attention to this aspect and better incorporation of it into the design of the study would have been beneficial in terms of helping ameliorate this variable. Making explicit the fact that a sustained and intense interaction between implementers and users of the intervention would increase the likelihood of its successful utilisation, and engaging the physics lecturers in discussion as to how this could be done (as became evident in their reflective discussions) could probably promote a sense of ownership and quicker adaption of the strategy as well as ensure relevance of the design solution (Landry, Amara, & Lamari, 2001).

Guideline 3: Negotiate professional development

> *If you want to design an intervention to promote reflection by physics lecturers on their instructional practice, then you are best advised to negotiate the structure and function of the professional development needed for the implementation of the intervention taking the specific epistemological and cultural identities of the users into account, rather than concentrating on generic teaching skills and presentational techniques because as indicated by Reitano and Sim (2005), effective professional development programs need to acknowledge the interrelatedness of knowledge, practice and situation Reitano and Sim (2005).*

Feedback from the respondents indicates that any professional development strategy accompanying the implementation of a designed intervention needs to be negotiated and not be in the form of time-consuming workshops. In the case of this study only brief face-to-face sessions where the philosophy behind the artefact, the methods needed to generate video data and score the video data with the protocol, as well as the integration of this data into the set of web-based resources, took place and access to internet was required. During these interactions conversations took place that enabled explanation and negotiation around the implementation of the strategy. During these sessions it seemed that it became apparent to the lecturers that the professional developer (education specialist) might be able to bring in physics education research insights which could fit the innate nature of pure physics classes, provide a resource set for self-directed learning which included space for the acknowledgement of the interrelatedness of their knowledge, practice and situation.

Guideline 4: Tailor dissemination to the audience

> *If you want to design an intervention to promote reflection by physics lecturers on their instructional practice, then you are best advised to actively disseminate information around the intervention, taking the innate disciplinary identity of the users into account because it is not advisable to waste time through unsuccessful attempts to transfer knowledge.*

This design guideline, which was supported by the reflective interview data, was initially motivated by prior research suggesting that dissemination (instead of just diffusion) of intervention should be tailored to the audience (Lomas, 1993). Lomas (1993) distinguishes between diffusion and dissemination, arguing that diffusion entails the passive process by which a growing body of information about an intervention initially is absorbed and acted upon by a small body of highly motivated users, whereas dissemination is seen as the process through which target groups are made aware of, receive, accept and use information and other interventions (Lomas, 1997). It became clear during the interviews that passive diffusion would be an ineffective way of bridging the gap between research and practice. However, when the conversation allowed for recognition of disciplinary and contextual factors, and was tailored to meet the lecturers' needs, the participants became actively engaged in the process in a manner that more closely fits Lomas' (1997) conception of dissemination.

Guideline 5: The intervention must be in the lecturers' zone of proximal implementation

If you want to design an intervention to promote reflection by physics lecturers on their instructional practice, then you are best advised to design the intervention and its associated activities in such a way that the intervention is in the lecturers' zone of proximal implementation. Working in the lecturers' 'zone of proximal implementation' (McKenney, 2013) helps ensure that the intervention is suitable for their current competencies, beliefs, intentions and attitudes towards the topic (Juuti & Lavonen, 2006) and that the intervention can feasibly be implemented.

This design guideline was motivated by prior research. Lagemann (2002) talks of generating 'usable knowledge' and creating interventions that serve teaching in practice, and Juuti and Lavonen (2006) as well as McKenney (2013) argue for design-based researchers to target innovations at changes that lecturers can implement with realistically sustainable amounts of guidance or collaboration – interventions within their "zone of proximal implementation" (McKenney, 2013, p. 2). Much of this sentiment was implicit in the lecturers comments during the interviews.

Guideline 6: Use design-based research as methodological framework

If you want to design an intervention to promote reflection by physics lecturers on their instructional practice, then you are best advised to utilise design-based research as a methodological framework to describe and shape the inquiry into the designed intervention because design-based research provides an avenue for utilising existing theories, developing them further and generating shareable theories. Design-based research also provides a natural and intuitive framework for investigations utilising interventions because it explicitly integrates theories in the *design of educational interventions and considers the implications for both practitioners and educational designers.*

This design guideline was motivated by writings of design-based research theorists, arguing that design-based research provides a framework for researching and documenting the professional learning of lecturers in authentic settings and connecting with outcomes of interest. Van den Akker et al. (2006, p. 5) characterise design research as:

- “Interventionist: the research aims at designing an intervention in the real world;
- Iterative: the research incorporates a cyclic approach of design, evaluation and revision;
- Process-oriented: a black box model of input-output measurement is avoided, the focus is on understanding and improving interventions;
- Utility-oriented: the merit of a design is measured, in part, by its practicality for users in real contexts; and
- Theory-oriented: the design is (at least partly) based upon theoretical propositions, and field testing of the design contributes to theory building”

making it suitable as methodological framework for a study with the aim of promoting reflection by physics lecturers on their instructional practice. In the context of this research, the explanatory nature of design-based research combined with its advisory nature, enabled me to gain theoretical insights into how reflection by lecturers’ could be triggered and promoted and in the process I not only addressed a complex problem in an ecological valid educational setting (triggering lecturers’ reflections on their instructional use of representations), but I also built a stronger connection between educational research and real-world problems (the design of the intervention and the formulation of the design principles illustrated in Figure 5.3).

Design-based research also enabled me to design a set of artefacts with the aim to influence the thinking and practice practices of the physics lecturers as users of the artefact. The consequential validity or the capabilities of constructs, models, methods and instantiations are equally crucial (Hevner et al. 2004) to the success of an intervention as its ecological validity. The design and function of the intervention became affordance enablers, but affordance is not predefined by the specific design and functionality of the tool – not in itself. The pedagogical usefulness is only determined when the individual user perceive the intervention's design and functionality helpful. As illustration, the integration of literature in the observation protocol offered lecturers possibilities to act (affordance) more intelligently (Juuti & Lavonen, 2006), while the profiles generated by applying the observational protocol to the observational data afforded the opportunity to refine or revise theory around the use of representations during physics instruction. The research instruments designed (the protocol and accompanying operational definition key, and the EOR taxonomy) provided the user with the material affordance to analyse the data.

Guideline 7: Consider the platform with the most suitable affordances for the presentation of the research results

> *If you want to design an intervention to promote reflection by physics lecturers on their instructional practice, then you are best advised to communicate the results of the intervention using the platform most suitable to your users' context because various platforms have different affordances to the user.*

This design guideline was motivated by the feedback received from lecturers during the interviews commenting on the usefulness of having access to video segments to observe their own practice and combine their observations with affordance theory. Affordance theory provide insights to the relationship between artefacts and the users of the artefacts, suggesting that design features of an artefact are affordance enablers (Gaver, 1996). The web-based resources, as well as the paper-based reference manual, offer material affordances to the lecturers (e.g. both afford the display of data, and afford input of data either in the form of markings on the paper or electronic input of data), but the web-based resources affords the display and storage of temporal data such as audio and video segments, durability and easier editing of stored data in a way that the paper-based resource cannot offer.

5. DESIGN PRINCIPLES

The identification, application, testing, and refinement of design principles were infused throughout the phases of this design-based research (Herrington & Reeves, 2011). Various design guidelines were identified in the grounding phase of the study (which consisted problem analysis, review of literature and the development of a conceptual framework for the study) (see section 3.6). These guidelines were necessary to inform the design of the preliminary artefact consisting of the observation protocol and the key of operational definitions. The procedural guidelines also informed the development of the research sequence followed during the instantiation of the artefact (see Figure 5.3).

Further guidelines (both procedural and design) were identified during the instantiation phase of the study (section 3.6). These guidelines led to the identification of a need to develop a measuring instrument (EOR taxonomy) to determine the level of achievement of the goal of the study (to stimulate introductory physics lectures to reflect on their instructional practice). It also identified future research opportunities based on the findings of this study (see Chapter 6).

At every stage of the research process, initial and evolving design principles informed and guided the direction and shape of the intervention, as well as its implementation and testing. This set of draft guidelines are reported in this chapter for comment by the research community as they require further refinement (which falls outside of the scope of this study). They are not “recipes for success” but are used principally “to help others select and apply the most appropriate substantive and procedural knowledge for specific design and development tasks in their own settings” (McKenney, Nieveen, & van den Akker, 2006, p. 73), and are abstracted to formulate the design principles lessons that were learned from this exploratory design-based research project.

Principle 1: Contextualise the problem and intervention (including any training or professional development associated with the implementation of the intervention).

Principle 2: Integrate domain theory into the design of the intervention by distilling kernel principles relevant to the context and goal of the study.

Principle 3: Provide alternative presentations of the results to afford greater cognitive engagement by the lecturers with the intervention rather than simple application.

Principle 4: Trigger evidence-based reflection (in contrast to memory-based reflection) via carefully selected activities based on easily retrievable evidence of practice, for example the use of video data, the presentation of the results in the form of various profiles, and an accessible protocol to analyse the level of reflection achieved.

Principle 5: Ground the design of the artefact, as well as the design sequences, on insights gained from the kernel theories of reflection, professional development and the instructional use of representations in physics.

Principle 6: Evaluate the intervention using a combined naturalistic and affordance approach that emphasises the socio-cultural nature as well as its meditational function in the promotion of reflective practice. Inclusion of affordance theory, particularly the relational viewpoint of Norman (1999), is helpful to understand the artefact features and how one can interact with the artefact. In this way design and function becomes affordance enablers (Gaver, 1996).

The design guidelines iteratively led to the design and development of two new design models (the observation protocol and the EOR taxonomy). The above principles can be illustrated diagrammatically as concentric circles that radiate from a core principle, the context where the intervention will be enacted (Figure 5.3). The natural environment characterise the invention (as oppose to acting as a controlling variable) (Barab & Squire, 2004). Radiating from the context in which the intervention is designed, follows the four design pillars upon which the intervention is build: The various types of theories contributing kernel theoretical principles to ground the design; evidence of the instantiation of the design; presentation platform chosen to communicate the design with the potential audience; and the measuring instrument to assess the quality of the outcome of the intervention (the levels of reflection achieved in the case of this study). Each of the four pillars has features that would offer practical and theoretical insight in the potential impact of the pillar on the eventual design.

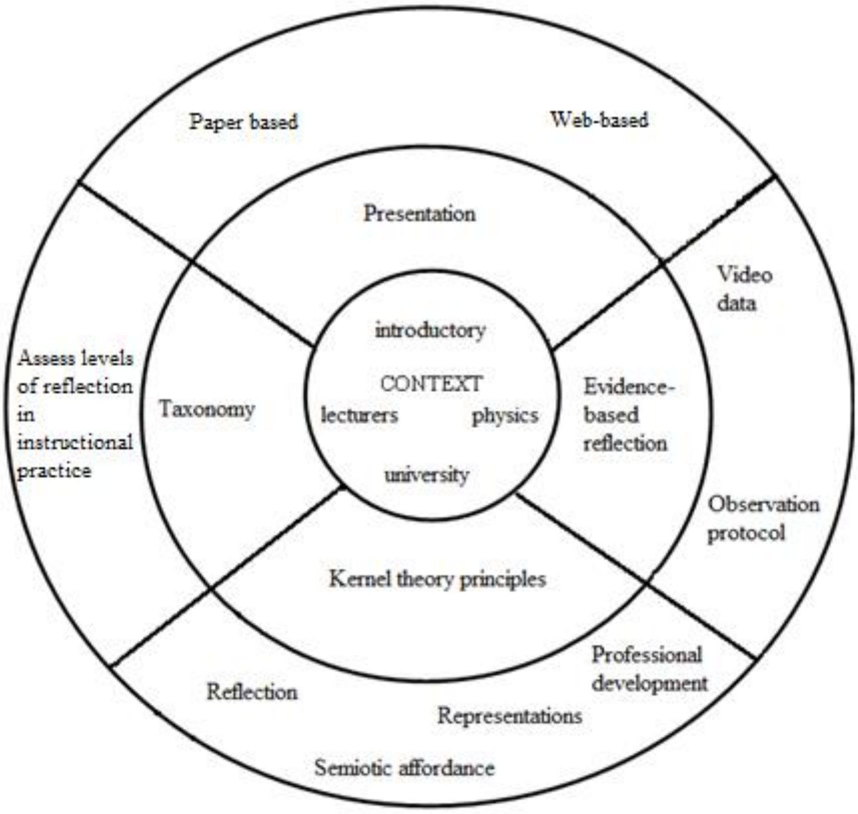


Figure 5.3: A concentric level illustration of the design principles of this study with the central principle of context, on which the four pillars of the intervention rest, followed by the facets of each pillar in the outer ring.

While Figure 5.3 illustrates the relationships between the various design principles, it is important that one should not consider the design principles as being final or ‘set in stone’ as the process of design-based research is itself a design (Dede, 2004). In the case of this research the design principles are simply tentative principles based on a single exploratory study and are in need of further refinement and re-design in order to be “informed reusable guidelines for others wishing to create their own solutions" to problems related to reflection in the domain of introductory physics (Herrington & Reeves, 2011, p. 598).

6. EVALUATION OF THE DESIGN-BASED RESEARCH PROCESS

Hevner et al. (2004) proposed seven guidelines to achieve an effective design-based research study, based on the principle that knowledge and understanding of a design problem and solution are acquired in the building and application of an artefact. In the section to follow the evaluation guidelines from (Hevner et al., 2004) are used to illustrate how the research (including both the process and the product) satisfies each of the criteria.

6.1 Problem relevance

The objective of design-based research is "to acquire knowledge and understanding that enable the development and implementation" of a solution to a relevant educational problem (Hevner et al., 2004, p. 84). Relevance of a research problem is situated in the constituent community (Hevner et al., 2004). An issue perceived as a problem in one community is not necessarily perceived as a similar problem in another community. To ensure the relevancy of my research problem it was grounded in physics education research literature, as well as in the context of the problem domain. The research problem identified in chapter one has three facets that need to be satisfied by the artefact(s) designed to alleviate the identified research problem. These facets are: the reluctance of physics lecturers to reflect on their instructional practice; the importance of learning and teaching from and with representations in physics; and the reluctance of physics lecturers to make use of physics education resources available to them. This study set out to exploit the opportunities available when using a design-based approach to the development of an intervention (artefact) to assist the lecturer to address the above mentioned research problem in a way that is sustainable both for practical and research purposes.

The relevance of the artefact was improved by paying attention to its practicality, with practicality meaning the "user-friendliness of the research findings" (Van Velzen, 2013, p. 792). The construct (the operational definitions) provided the lecturers with the language or terminology needed to think about the research problem, while the observation protocol, with methods to analyse the problem imbedded in it, addressed the research problem. The instantiation of the artefacts, which demonstrated to the lecturers how the research problem could be affected by the implementation of the artefacts, helped affirm the relevance of the strategy (Hevner et al., 2004). The practicality of the research findings were affirmed by the lecturers during interviews after both instantiations, with only one of the lecturers not convinced of the practicality of the research findings because he expected them to provide a quantitative measure of his instructional use of representations.

On a more philosophical level, relevance of the research lies in the fact that physics is considered to be a fundamental subject. Given the current low pass rate of most physics courses, the perception is that it is a difficult subject and the South African Institute for Physics has identified the activities that take during physics lectures as a problem worthy of research. As such, it appears self-evident that the identified research problem is one of relevance not only to the individual physics lecturer who loves his or her subject, but also to the wider physics community.

6.2 Research rigour

> *"Design-based research requires the application of rigorous methods in both the construction and evaluation of the designed artefact"*

(Hevner et al., 2004, p. 87).

Rigour is an expected and accepted principle of academic research and relates to the research process and how the research process impacts upon the resulting claims of knowledge. In this study Shavelson and Towne's (2002) guiding principles were adhered to in accordance with Plomp's (2007) suggestions that design-based researchers, like all researchers, need to ensure the required rigour to support their findings. These guidelines are: posing significant questions; linking research to relevant theory; using methods that permit direct investigation of the problem; providing a coherent and explicit chain of reasoning; and explicitly exposing what has been done to encourage professional scrutiny and critique. The strength of design-based research is that it aligns "theory, treatments and measurement" (Hoadley, 2004), and balances rigour and relevance (Hevner et al., 2004), In turn, Spencer (2009) notes that rigour can be achieved by adopting a reflective stance. These notions demanded that I provide answers to the following two questions: 'How did I ensure rigour in the construction of the artefact or intervention?' and 'How did I ensure rigour in the evaluation of the artefact?'

Rigour in the construction of the artefact was derived from the effective use of the knowledge base (Hevner et al., 2004). The study was grounded in the domain theories of reflective practice, semiotic affordance theory and the instructional use of representations in physics. These research areas have a long history of formal, rigorous results. The kernel theories (semiotic affordance theory, reflective practice and instructional use of re[presentations) aligned with the identified problem, provided assistance with the identification and formulation of the research objectives and research questions. the research questions and objective were not only significant, but also linked to theory – satisfying two of the criteria formulated by Shavelson and Towne (2002).

Rigour in the context of the empirical work was ensured by the selection and development of the most appropriate methods and instruments to collect the data that answered the research questions. Research design phases, one of the characteristics of design-based research, were used as framework for reflecting on the various stages in the research process (Easterday, Rees Lewis, & Gerber, 2014). The design phases helped me to think precisely, as well as acting as a tool to make the design logic explicit to the reader of the research. The phases allowed me to explain which methods I borrowed from other methodologies during the various phases (e.g. video-stimulated reflection interviews, content analysis of video data generated from systematic classroom observation, etc.) aligning the design-based approach used for this study to its pragmatic nature. Similarly the phases were used as analytical tool for judging design processes and potential contributions (Easterday et al., 2014). The design of the research, combined with a discussion of the validity and reliability strategies employed to ensure rigour, were discussed in Chapter three (section 9). Despite the fact that design-based researchers all agree that the findings of a design-based study cannot be generalised from a sample to a large population (Alghamdi & Li, 2013; Barab & Squire, 2004; Plomp, 2007) the formulation of various design principles enable the findings of a study such as this one to be generally transferable from one context to another (Alghamdi & Li, 2013). While validity is important, it is also important to focus on the usefulness of the research outcome (Yee, 2012). "Usefulness of design knowledge relates to how it benefits the understanding of the field, moving from factual knowledge to tacit knowledge, and the application of knowledge" (Yee, 2012, p. 488). The usefulness of the design knowledge generated in this study can be said to have been demonstrated by the use of visual devices that address fellow researchers "in a familiar semantic code" (Yee, 2012, p. 488).

Ensuring rigour in a design-based research project also requires a reflection on the research process followed to interrogate whether a coherent and explicit chain of reasoning is present. A conceptualisation of the design sequence is illustrated in Figure 5.4. Throughout the research process the stated ethical values were upheld, adding to the rigour of the research process. These values include, for example, fair and honest dealings with research participants.

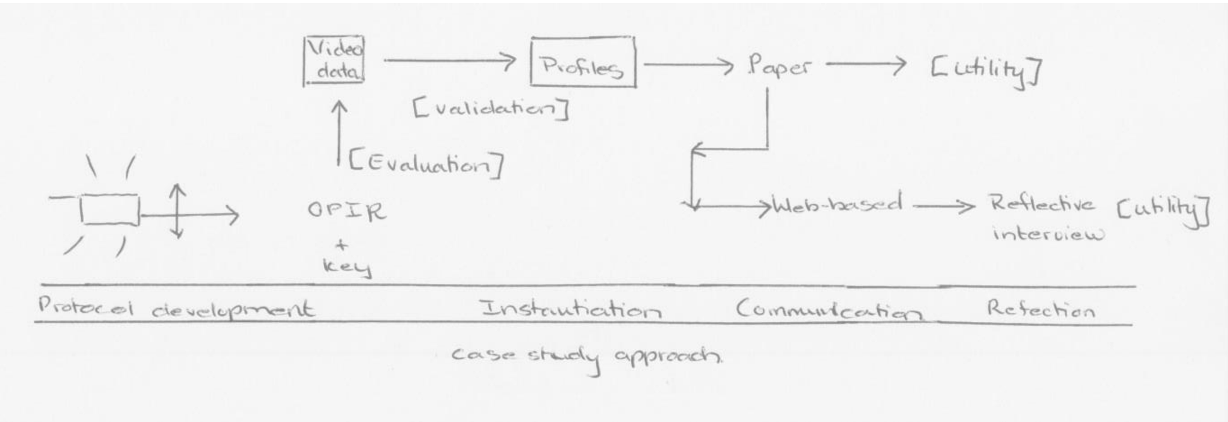


Figure 5.4: Illustration of the chain of reasoning used in the design study

6.3 Design as a search process

As stated earlier, design is essentially a search process to find an effective solution to an identified research problem (Hevner et al., 2004). The search for design principles (both substantive and methodological) was partly deduced from known theories and partly extracted from the prototype itself. The search for a solution to the research problem involved a review and careful analysis of already available interventions and 'kernel' theories for available interventions to generate ideas around reflection in the context of higher education teaching. It also looked for the availability of instruments to describe the instructional use of representations in introductory physics, as well as for design principles documented in literature on features or characteristics that would have the possibility of affording reflection by lecturers on their instructional practice.

Another example of how the development of the design involved a search process is the development of the EOR taxonomy. The purpose of this process was to find an instrument for assessing the level of reflection achieved by lecturers as a form of summative assessment of their learning after participating in the intervention. A search for a possible solution to address this purpose started with analysing the SOLO taxonomy developed by (Biggs & Collis, 1982) for principles of assessing quality of response or outcome; followed by a search for various descriptions of levels of reflection with a particular focus on descriptors for instructional practice. This resulted in the theoretical construct describing the levels of reflective practice specifically adapted to the context of reflection on higher education instructional practice (see Table 2.1 in Chapter two). A further search for a more simplistic tool lead to the adaptation of the levels of reflection contained in Table 2.1 to result in the EOR taxonomy presented in Chapter four and in the reference manual (Appendix B).

6.4 Design as artefact

The result of design-based research is by definition a purposeful artefact (in the form of a construct, model, method and instantiation) created to address a research problem (Hevner et al., 2004). These authors acknowledge that artefacts constructed in design-based research are rarely full-grown interventions that are used in practice, but rather innovations that "define the ideas, practices, technical capabilities and products through which the analysis, design, implementation, and use of [educational interventions] can be effectively and efficiently accomplished" (Hevner et al., 2004, p. 83 citing Denning, 1997 and Tsichritzis, 1998).

The principal output of the study is a framework for the evaluation of reflection in the context of the instructional use of representations in introductory physics classes. Two artefacts were developed in the course of this study. The first artefact is a reference manual (see Appendix B) containing the construct (explanatory key), the model (the observation protocol) and the methods. The viability of the artefact lies in the fact that it could be expressed and applied to a problem domain. Further, its feasibility was argued from the instantiation of the artefacts resulting in the generation of the various profiles represented in the web-based set of resources (the second artefact) (see Appendix C).

The construct or explanatory key representing the language and vocabulary in which the instructional use of representations in introductory physics classes, was defined and communicated. The construct was integrated in the model by means of information statements embedded in the protocol and the representational repertoire (see Figure 4.13). The observation protocol represents the model for the description or documentation of lecturers' use of representations during their physics instruction. The model consists of three sections: background, representational repertoire and instructional strategies. The model and construct was instantiated using a case study approach and yielded the second artefact developed in the course of the study, namely the web-based resource for physics lecturers (see Appendix C). This process was discussed in chapter three with the results of the instantiation offered in Chapter four.

6.5 Design evaluation

One of the requirements of rigorous design-based research is the evaluation of the design artefact itself; as explained by Hevner et al. (2004):

> *"The utility, quality and efficacy of a design artefact must be rigorously demonstrated via well-executed evaluation methods. ... [A] design artefact is complete and effective when it satisfies the requirements and constraints of the problem it was meant to solve"*

(Hevner et al., 2004, pp. 347, 352).

When deciding on the evaluation approach to choose for the evaluation of the designed intervention the choice was between an artificial evaluation approach (for example the use of field experiment or simulations) or a naturalistic evaluation approach (Venable, 2006). I chose a naturalistic case study evaluation approach to explore how well or poorly the solution to the research problem worked in its real environment with all the complexities of human practice in real life organisations (Venable, 2006). The evaluation was empirical and the results were used to feed back to the design. It must be noted that, as was highlighted by Venable (2006), the evaluations were mostly based on the participants' perceptions and opinions about the effectiveness and usefulness of the intervention rather than a measure of the object itself. In addition, the EOR taxonomy was developed to evaluate the levels of reflection achieved by the lecturers after they experienced the intervention. This instrument served as a second measure of the effectiveness of the intervention to solve the problem (promote reflection by lecturers).

A stage-dependent evaluation strategy (Kelly, 2004) was used where I chose different evaluation methods depending on the stage of the design (early developmental/grounding stage). To demonstrate the utility, quality and efficacy of the design artefact during the early developmental stage, formative evaluation was used to improve the quality of the intervention under development (Van den Akker et al., 1999). Formative evaluation took place iteratively throughout the design and development process, focusing on information richness (focusing on salience an meaningfulness of suggestions in how to make an intervention stronger) and efficiency by collecting just enough data to get feedback that can have an impact on the development of the artefact, but not slowing the process down with 'tons' of data (Easterday et al., 2014; Van den Akker, 1999). For example, after the first instantiation of the observation protocol, an interview was conducted with the first participant whose data was analysed (instead of interviewing all the participants) to elicit feedback on the utility and efficacy of the resultant profiles generated in the analysis of his data. His feedback resulted in the development of the web-based set of resources (one of the primary outcomes of the study) to improve access and engagement with the results of the data analysis by the lecturers. Another example of formative assessment was the on-going refinement of the list of operational definitions, resulting in the final list included in the reference manual (Appendix B).

The amended design products underwent a pre-summative evaluation during the second iteration, resulting in a plausible, well-grounded set of design guidelines and artefact with some evidence of the artefact's usability performance in the setting it was designed for. A case study approach was chosen to systematically and rigorously evaluate the usability of the artefact. The case study acted as a pre-summative evaluation implemented to help evaluate the feasibility of these designed artefacts in the second stage with its more plausible, well-grounded prototype artefact, finalising the prototype artefact.

The artefact designed in the study is a prototype and not a matured artefact ready for scaling up and field testing. Empirical testing of the designed artefact in various contexts with the aim of full-scale implementation of the artefact (summative evaluation) therefore falls outside the scope of this study. As such, this design-based research study can be described as an exploratory design study (Van den Akker et al., 1999) with an emphasis on a preliminary investigation into the feasibility of an artefact designed to promote reflection by physics lecturers.

During the development and research process the emphasis on quality criteria shifted from validity to practicality and effectiveness (Van den Akker et al., 1999). The methods and techniques I chose for both formative and pre-summative evaluation were attuned to this shift in criteria. Various techniques were used during the grounding and the development stages of the study such as ensuring ecological validity, treatment validity (ensuring that he artefact developed was accurately aligned with the theories it represents), systemic validity (not only design research that is a fair test of the theories, but communicating the theories in such a way that they are true to the inferences used to prove them) and consequential validity (considering how the interpreted results of the research will be applied in practice) (Hoadley, 2004) (see section 9.1 in Chapter three for a detailed discussion).

Practicality, or the extent to which users consider the intervention as appealing and usable in ‘normal’ conditions (Van den Akker et al., 1999), was established in chapter four (section 4.2.1). The effectiveness of the artefact to address the research problem of promoting reflection by the physics lecturers on the instructional affordances offered by their instructional use of representations was evaluated during the video stimulated reflection interviews conducted after the second instantiation of the artefact. Evidence were presented indicating that the lecturers did reflect on their instructional practices and that their level of reflection could be successfully measured using the EOR taxonomy designed specifically for this purpose.

6.6 Research contributions

> *"Effective design-based research must provide clear contributions in the areas of the design artefact [the research product], design construction knowledge (i.e. foundations), and/or design evaluation knowledge (i.e. methodologies)"*
>
> (Hevner et al., 2004, p. 87).

The key contributions of this study are the means used for the development, specification and evaluation of a set of artefacts and the viability of this approach and the artefacts produced. As mentioned earlier, 'the artefact' in this study can be described as a framework comprising of; an observation protocol; an explanatory key accompanying the protocol; a method (description of the research steps needed to apply the above resources in the context of instructional practice in introductory physics classes) for the implementation of the protocol; two alternative communication platforms, namely a paper- based (Appendix B) and a web-based set of resources (Appendix C), and; a measurement tool to assess the outcome of the implementation of the protocol.

The application of the above set of resources allows one to produce various profiles of an individual lecturer's instructional use of representations, namely a profile of the lecturers' representational repertoire, a comparison of the lecturer's instructional repertoire compared to the representational modes identified in physics education literature as being beneficial for introductory physics instruction and, lastly, a typology of instructional practices distinguishing between traditional practice and contemporary practice.

The framework is grounded in foundation or kernel theories (descriptive theories of reflective practice, semiotic affordance theory and theory on instructional use of representations in physics) and extends the current theoretical insights available on the how to merge theoretical insights on promoting reflective practice with the practical insights on the instructional use of representations in introductory physics classes. At the same time the research sequence used to achieve the promotion of reflection contributes to design process knowledge by providing a set of methodological guidelines for use by other design researchers. The contextualisation of the design study and the design of specific products tailored for the context of this study satisfy the requirement for uniqueness expected of a research-based artefact.

Contributions from this research are illustrated using the framework of Hubka and Eder (1988) which is characterised by four aspects: (i) statements about the artefact, (ii) statements about the design process, (iii) descriptive statements, and (iv) prescriptive statements (see Figure 5.6). The statements about the artefact can be sub-divided into knowledge (scientific, experiential, societal, technological, etc.), and theories about the discipline. The statements on the design process can be sub-divided into two areas: design methodology, and theory of design processes.

The contributions of this study are based on descriptive theories of semiotic affordance and reflection on instructional practice and the instructional use of representations in physics. As one of the objectives of this project was to contribute to the understanding of the implications of the intersubjectivity nature of the intervention, and to provide alternative methods for product representation in the context of higher education teaching, the combination of these theories in an interdisciplinary project to answer the research questions posed in chapter one, has enabled wider understandings of their use in practice. The contribution can therefore be mapped as falling in the categories of design knowledge (the artefact is designed for particular purpose) and design process knowledge (providing a set of methodological guidelines on how to implement the artefact).

6.7 Communication of research

"The problem, the artefact, and its utility should be presented in a manner such that the implications for research and practice are clear" (Hevner et al., 2004, p. 91).

The main vehicle available for dissemination of the intervention is the cluster of webpages created to act as a resource for researchers and designers. The second vehicle for dissemination is the reference manual for the framework for promotion of reflection on the instructional use of representations in physics (Appendix B). The results of the design-based research project will be communicated to the research community at large in the form of papers at physics education and general physics conferences and peer-reviewed journal articles. Although the presentation of this research is aimed at an audience familiar with physics and physics education research, the study also contains important and useful information for academic staff development practitioners who are familiar with, or interested in, the notions of reflective practice and semiotic affordance theories. As such, it is believed that the outcome of this interdisciplinary design study should be of interest to all three groups of stakeholder, namely physics purists, physics education researchers, and academic staff development practitioners.

7. CHAPTER SUMMARY

Firstly, this chapter provided reflections on the main contributions of the research process; namely the methodology, the research framework and the domain theories, to create design principles for use in further research on this project or by researchers in projects situated in a similar class of contexts. Secondly, it assessed the design-based research process against the seven design-based research guidelines advanced by Hevner et al. (2004) and shows that the research has met the requisite features or elements of these guidelines in that it; produced an artefact (the framework with its construct, method and model, plus the web-based resource to represent the results of applying the framework); it tackled a persistent, relevant and widespread problem (reflection by physics lecturers on their instructional practice) through an iterative development and refinement cycle with a rigorous evaluation of the artefact (case study with five participants) which draws upon and adds to the knowledge base (knowledge utilisation theory) resulting in a purposeful, innovative and generic solution to the problem at hand.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

1. INTRODUCTION

As repeatedly stated, this design-based research study focused on designing a reliable, valid and practically useful artefact (framework/strategy) to trigger introductory physics lecturers' reflections on their instructional use of representations. The initiative was partly based on growing awareness in the physics education research community about the importance of using representations in physics teaching, and partly on the need for lecturers to reflect on their practice. The principal and sub-questions were framed as explicit tests of the designed artefact's effects and whether a design-based approach process was suitable to generate a valid, reliable and useful solution to the research problem.

As an underpinning feature of the research was to generate usable knowledge in the form of design principles, the objectives of the study were to identify a suitable strategy to engage physics lecturers in reflection on their instructional use of representations, create a systematically and rigorously designed product, generate data that indicate the validity and effectiveness of the product, establish the degree to which the strategy can be successfully implemented, and determine whether the intervention as conceived is able to achieve its goal of engaging lecturers in reflection on their instructional practice.

2. MEETING THE RESEARCH OBJECTIVES

A thorough grounding of the design in various theoretical foundations enabled research literature to guide the conceptualisation of the proposed strategy for engaging physics lecturers in reflection. Semiotic affordance theory provided the orienting framework to the conceptualisation of the proposed strategy. Reflective practice focusing on the instructional affordances of the use of representations in introductory physics classes served as the domain-specific action framework. This grounding led to attainment of the second objective, which was to create a systematically and rigorously designed product intended to meet the research design goals. This objective was achieved by means of the development of two key products, a framework for the promotion of reflection amongst physics lectures and a web-based platform to disseminate the designed artefact (construct, method, model and instantiation). The artefact enabled specific insights on the nature of research-based representational repertoires and instructional strategies relevant to introductory physics lecturers.

The data which indicate the validity and usefulness of the product were generated by applying the observation protocol and operational definitions as *a priori* codes during the analysis of video data of lecturers' instructional use of representations. Being able to describe the lecturers' use of representations during their instruction by means of three profiles of their instructional practice acted as 'proof-of-concept' for the designed artefact (the construct, model and methods) and as an indicator of its validity. Although the creation of the artefact served as proof-of-concept, the need to validate it remained (Hoadley, 2004) notion of alignment amongst observation data, measurement instruments and theoretical paradigms (Kirk & Miller, 1986) was used to validate the instantiation. This aspect was achieved via a clear chain of evidence provided by the description of the research sequence and the design framework (see Chapter five sections 3 and 4). The usefulness of the artefact was established via the lecturers' reflections and its ability to assess levels of reflection when using the EOR taxonomy (described in Chapter four).

The need to establish whether the strategy designed to trigger physics lecturers' reflection on their instructional use of representations could be successfully implemented was addressed firstly by using the instantiation results revise the dissemination platform as a web-based set of resources (see Chapter four). Assessment of levels of reflection achieved by the lecturers during their video-stimulated reflection interviews provided indicators of the success of the designed strategy. Implementation was, however, not free of challenges. The instantiation and evaluation stages revealed the impact that contextual factors play in the implementation of interventions – especially the participants' disciplinary identity (see design guidelines in Chapter five). Finally, the objectives of determining whether the intervention as conceived was able to achieve its goal of influencing lecturers levels of reflection on their instructional practice was met by assessing the extent of the reflection displayed/achieved using the EOR taxonomy tool.

3. ANSWERING THE RESEARCH QUESTIONS

The answer to the principal research question, namely the ways in which reflection on instructional practices by introductory physics lectures can be influenced using a design-based research approach is framed by the answers to the sub-questions posed. The first sub-question on how lecturers might be engaged in reflection on their instructional use of representations was addressed by meeting the first two objectives of the study (grounding and creating a systematically and rigorously designed product).

Although the lecturers' reactions were initially mixed in terms of the value of the artefact (intervention strategy framework), an increase in positive utterances over time during the reflection sessions revealed a growing (sometimes grudging) appreciation of the potential of the process. By the end of the study, all but one lecturer appeared convinced to a greater or lesser degree of the value of using the designed product and processes to assist them reflect on their practice. This finding answers the sub-question as to how the intervention strategy was received by the participants.

Finally, the answer to the third sub-question, which asked whether the intervention as conceived within a design-based research approach triggered physics lecturers' reflection, is answered by the fact that, in the main, the lecturers believed that having valid visual evidence in the form provided acted as a suitable trigger for reflection. The data generated also show that the quality of these reflections could be assessed by means of the designed EOR taxonomy. These findings support those of Poole, Harman, and Deden (1998, p. 274) who so aptly stated: "without good information, academics, like most people, are capable of self-deception".

The answers to the sub-questions (which are stated in much greater detail in Chapter five) all contribute to answering the main research question and it can be concluded that the strategy designed to trigger reflection did have a positive influence on lecturers' reflections on the instructional affordances of their use of representations. An interesting aspect of the process was the emergence of three types of discourse in their reflections, namely a student deficit discourse; an academic discourse; and a personal discourse (see Chapter four, section 6.4.2). Apart from indications of discourse development, the study provides evidence of the possibility of meaningfully measuring levels of reflection by using the EOR taxonomy designed specifically for this purpose.

At this stage it is important to note that this design study was driven by the dual purpose of not only understanding, documenting and interpreting, but also of improving educational practice and opportunity. New knowledge was gained regarding the link between the theory of learning with and from representations and the instructional use of representations in a higher education context. However, the issue of resistance to the dissemination of physics education reforms remains an important unsolved problem for the physics instruction community (Henderson & Dancy, 2008).

Working in an interdisciplinary context is intricate, but it has been shown in this instance to be able to make a contribution to domain theory through the formulation of a set of design principles. The contribution of the study can therefore be mapped as falling in the categories of design knowledge (the artefact is designed for particular purpose) and design process knowledge (providing a set of methodological guidelines on how to implement the artefact).

4. DELIMITATIONS AND LIMITATIONS OF STUDY

The aim of the study was to design and develop an artefact to investigate whether such an approach could influence reflection by physics lecturers on the instructional affordances of the use of representations in their practice. It is cross- sectional in nature and makes no claim in terms of tracing changes in practice over a period of time. The target sample consisted only of a modest number of participants during the instantiation process, namely five lecturers teaching introductory physics at one comprehensive university (a university offering both vocational and research-based qualifications). It must also be remembered that another teaching context (e.g. Life Sciences or Mathematics) will likely include different contexts, repertoires and instructional strategies.

Furthermore, the research was conducted as doctoral research with a limitation in the time allocated for the study, which is not an ideal context for design-based studies that are iterative in nature and require long-term commitment to continually refine theoretical claims. As such, the findings of this study should be considered as just a start of a long term iteration process in the larger scheme of research to influence the reflection of physics lecturers on the instructional affordance of their use of representations. It is a prototype development study – a 'proof-of-concept' type of research.

5. RECOMMENDATIONS FOR FUTURE RESEARCH

Apart from the more obvious recommendations such as to include more participants in the instantiation and evaluation of the artefacts, more systematic in-depth interviews to enhance the feasibility and applicability of the designed artefacts, and longitudinal research to trace changes in practice over time, an important next step in the life cycle of this research project would be to explore the sustainability, transferability, and generalisability of the outcomes of the design. While it was initially important to generate data in a natural setting, the design now needs to be tested within more controlled studies to better establish theoretical claims. Although the design principles, and enacted components of the intervention, were applied in a second iteration, it remains to be demonstrated that the outcomes are sustainable without the presence of the design researcher. In addition, an important goal that any educational design-based research project should pursue is enabling the application of the research outcomes beyond local contexts (Gravemeijer & Cobb, 2006), i.e. in varied settings and wider domains (Plomp & Nieveen, 2013). Some of these wider settings could for example include various engineering departments (those whose underpinning subject domain is still physics, e.g. electrical engineering) or both physics and engineering lecturers at other universities.

The platform of communication and dissemination of the artefact could be developed further to include a data base which allows retrospective analysis of the profiles over time. The interactivity of the web pages could also be enhanced by designing them to automatically update profiles based on data added by the lecturers (such as when they analyse a video recording of a new class they taught) and manuals could be developed cooperatively with the users as self-directed learning units. All of these design modifications provide opportunities for further research. Deeper interrogation of influencing variables should also benefit the process, as will considering the work of Knott and Wildavsky (1980) and Stone (2002) who emphasise considering the stages of knowledge utilisation that influence design

6. FINAL REFLECTION AND CONCLUDING REMARKS

A design-based research approach that used a combination of developing theory, descriptions of successful design processes, and prescriptions of successful design solutions (Juuti & Lavonen, 2006, p. 56) was implemented in this study because of its interventionists, iterative process, utility and theory oriented characteristics (Van den Akker et al., 2006). By applying existing theoretical knowledge, it was possible to create and test methods and processes specifically related to reflection on instructional practice.

The goal of positively influencing lecturers' reflections on their practice was achieved through the implementation of a three-phase design-based research approach which enabled the verification of a framework for describing the instructional practice of lecturers and the assessment of the quality of their reflections. Nevertheless, the framework described is but one suggested means of addressing the research problem identified and, taking advice from the domain of engineering design, it is important to remember that a design seldom reaches finality – there are numerous possibilities to explore in future research projects as illustrated so aptly by the following extract:

> "Artefacts … are material stories; with routing devices [like scripts] and affordances …, which guides the 'reader' without fully determining his/her movements." … "Thus, 'reading' of an artefact is a practice, building on affordances, rather than being dependent on conventional texts. Such 'readings' [being routed and shaped] happen between artefact and user, and behind them, the designer as 'writer' [inscribing and shaping] of the original story. Material stories or narratives create agendas and storylines that continue into the future. Designers, clearly, are seen as 'writers'. Just as in writing novels, the writer is not in complete mastery of his characters; the unfolding storyline has its own dynamics (an evolving reality)"

(Rip, 2009, pp. 412-414).

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APPENDIX A

ETHICS AND PARTICIPANT INFORMATION FORMS

Ethical clearance from Research Ethics Committee (Human) – NMMU

Lecturer information on project

Lecturer consent form

Ethical clearance from Research Ethics Committee (Human) - NMMU

Nelson Mandela Metropolitan University

for tomorrow

• PO Box 77000 • Nelson Mandela Metropolitan University
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Chairperson: Research Ethics Committee (Human)
Tel: +27 (0)41 504-2235

Ref: [H13-EDU-ERE-004/Approval]

RECH Secretariat: Mrs U Spies

30 July 2013

Prof P Webb
Faculty of Education
South Campus

Dear Prof Webb

THE USE OF MULTIPLE REPRESENTATIONS IN INTRODUCTORY PHYSICS COURSES: THE CASE OF NMMU STUDENT ABILITIES AND ATTITUDES IN TERMS OF PROBLEM SOLVING

PRP: Prof P Webb
PI: Ms E Lombard

Your above-entitled application for ethics approval served at the Research Ethics Committee (Human).

We take pleasure in informing you that the application was approved by the Committee.

The ethics clearance reference number is **H13-EDU-ERE-004**, and is valid for three years. Please inform the REC-H, via your faculty representative, if any changes (particularly in the methodology) occur during this time. An annual affirmation to the effect that the protocols in use are still those for which approval was granted, will be required from you. You will be reminded timeously of this responsibility, and will receive the necessary documentation well in advance of any deadline.

We wish you well with the project. Please inform your co-investigators of the outcome, and convey our best wishes.

Yours sincerely

Prof CB Cilliers
Chairperson: Research Ethics Committee (Human)

cc: Department of Research Capacity Development
Faculty Officer: Education

Nelson Mandela Metropolitan University

for tomorrow

Lecturer information on project

Principle Investigator: Mrs EH Lombard, Faculty of Education, South Campus, NMMU

Contact details: 041 504 4578 (w) e-mail: elsa.lombard@nmmu.ac.za

Ethics reference number: H13-EDU-ERE-004

Title of the research project: The use of multiple representations in introductory physics courses: The case of NMMU student ability and attitudes in terms of problem solving (original title).

Dear colleague

I am a Physics Education PhD student registered in the Faculty of Education. I am inviting you to take part in a research study that will focus on the introductory physics lecturers' use of representations and their reflection on the instructional affordance of their representational practice.

The purpose of the study is to design and develop an objective, valid, reliable and practically applicable artefact to measure the instructional use of representations by lecturers in introductory physics classes and to trigger and enable reflection on their instructional affordances. The reflective tool would assist introductory physics lecturers to:

i. Identify the areas of their own use or representations where they do not implement research based knowledge around teaching and learning with and from representations,

ii. reflect on the instructional affordances offered.

To design the envisaged artefact, permission is sought to conduct classroom observation and to video record the observed classroom practice. The focus will only be on the didactical activities of the lecturer and not on the students. The classroom observation will take place during the normal lecture times allocated to the courses as part of their normal time-table. The number of observations per lecturer will be negotiated with each individual lecturer.

All information collected will be kept strictly confidential and will only be used for the purpose of scientific research. The findings will be anonymised to protect the identity of the individual lecturers and keep their video recordings confidential (except if you are giving specific consent for your identity to be revealed. Quotations used as evidence in the reporting of the research findings will be anonymised.

If you decide to take part in the research you are free to withdraw at any time and without giving a reason.

Thank you for taking the time to read the information sheet.

Elsa Lombard

Lecturer consent form

Ethics reference number: H13-EDU-ERE-004

Principle Investigator: Mrs EH Lombard, Faculty of Education, South Campus, NMMU

Title of the research project: The use of multiple representations in introductory physics courses: The case of NMMU student ability and attitudes in terms of problem solving.

1. I confirm that I have read and understand the information sheet for the above study and have had the opportunity to ask questions.
2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving reason.
3. I agree to take part of the above study.

	Please tick box Yes	No
4. I agree to the classroom observation being digitally recorded.	☐	☐
5. I agree to the use of anonymised quotes in publications.	☐	☐
6. I agree that the classroom data may be used in future research	☐	☐

Name of participant	Date	Signature

Name of researcher	Date	Signature

APPENDIX B

REFERENCE MANUAL

Framework for the Promotion of Reflection on the Instructional use of Representations in Physics

APPENDIX C

INTERVIEW PROTOCOL

Nelson Mandela Metropolitan University

for tomorrow

Interview protocol

Introduction

Thank you for agreeing to participate in this interview I am talking to you today about your experience with participating in this research project. I would like to audio record this conversation.

I will also use some of these data as part of my dissertation research. Please feel free to ask for clarification of any question that you do not understand. Also, you should not feel confined to answer only the questions asked. They are meant to be conversation starters."

[*Have the interviewee read the consent form, answer any questions, have interviewee sign form and give them copy of form. Turn on the tape recorder and test it.*]

Questions

Section I [validation of the analysis done in phase one of study]

1. Do you think that the profile and video segments provided beforehand is a fair description of your instructional practice?
    a. If your answer is yes, please motivate why.
    b. If your answer is no, please explain why.

Section II – Reflections on the instructional affordance of the representations used during instruction

2. Can you please talk me through the representations you have used during your lecture?
3. What did you want to achieve when you decided to do it in this way?
4. What did you think the students would gain from your use of representations?

    [Prompt by referring to specific sets of representations or to specific content units as identified for each individual participant]

Section III - focused on whether the insight gained by the lecturer about their own teaching practice can be of practical use to the lecturers in their professional career as a lecturer.

5. The use of videotapes in which a lecturer watch and discuss with a mediator or critical friend episodes of their classroom practice has been shown to be a useful tool in professional development. What value do you see in this sort of activity?
    a. If you see no value in this sort of activity, please explain why not.
6. Can you suggest other ways of doing the VSR that would have helped you in your professional learning?
7. How useful is the profile of your instructional use of representations to your own awareness of your teaching practice?
8. Do you think that participants in a study like this one you participated in, requires training in using these reflective tools?
    a. If yes, what type of training?
    b. If no – explain why no training is needed.
9. Do you think that the VSR technique was an effective trigger for reflection?
    a. If your answer is yes, please explain why.
    b. If your answer is no, please explain why not.

10. Do you think this process was effective as a form of professional learning?
    a. If your answer is yes, please explain why.
    b. If your answer is no, please explain why not.
11. Any further comments you want to make about VSR or the research process?

Closing statement

Can I ask permission to contact you via e-mail would the need for any further clarification or additional questions arise? Please remember that you are under no obligation to answer a question if you do not feel to do so.

"Thank you for participating in this interview."

APPENDIX D

COMPACT DISK WITH WEB-BASED RESOURCES

Adhering to the ethical practice of protecting the identity of the participants the web-based resource cannot be made available. Contact me if you are interested in the resource.