UNIVERSITY OF
LINCOLN

The effectiveness of a must-have practical work in tertiary Life Sciences' education: A case study of undergraduate courses at a British university

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A thesis submitted in partial fulfilment of the requirements of the
University of Lincoln for the degree of Doctor of Philosophy

University of Lincoln
School of Education
College of Social Sciences

August 2022

“I have been impressed with the urgency of doing. Knowing is not enough; we must apply. Being willing is not enough; we must do.”

Leonardo da Vinci

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The thesis was prepared in accordance to the University of Lincoln regulations and has not been submitted in any previous application for a degree, except as specified.

Parts of this work as presented in Chapters 1-6 of the thesis have appeared in publications as follows:

Constantinou,M.,Abrahams,I. (2019). Does it really work then? Practical Work in Undergraduate Science Education. New Perspectives in Science Education, Florence Italy

Constantinou, M & Fotou, N. (2020). Hands on or hands off? A look into undergraduate life sciences practical work. In: New Perspectives in Science Education, 19-20 March 2020, Florence,Italy.

Constantinou,M & Fotou,N. (2020). Practical work: A must-have in undergraduate Life Sciences, but does it really work? MDPI Information, 11 (9),401

Constantinou,M (2022). No man is an island, neither practical work is: A case study into undergraduate Life Sciences. In: New Perspectives in Science Education, Florence Italy, 17-18 March 2022

This thesis is dedicated to my parents and loved ones. For their endless love unconditional support, encouragement and faith in me.

This thesis is also dedicated to my grandmother, for in her last moments, she was awaiting me to submit my 'school work' for my doctorate.

Acknowledgements

They say that ‘ no man is an island ‘ (John Donne, 1624). Indeed, I would not have been able to complete this thesis without the unconditional support of my colleagues, mentors, family and friends.

Initially, I would like to express my sincere gratitude for the support, guidance, mentorship and encouragement I have received from my supervisors, Dr Nikolaos Fotou and Dr Anita Backhouse.

Nick, thank you for the endless hours of fruitful discussions and wise advise. Your mentorship and friendship allowed me to shape myself as a young academic and build resilience towards achieving my goals. - “Whatever you set your mind to, become stubborn and do it” (2019)

Anita, your calm energy and your firm attitude helped me to discipline myself and reach my goals. Your support at conferences and in the department’s corridor during hours of inevitable PhD crisis strengthened my confidence, encouraged me and helped me believe and trust the journey towards developing as a professional.

My thanks are extended to my colleagues and members of staff at the School of Education for their kindness, guidance, experienced research advice, encouragement and support throughout the years; Joss, Terence, Carol, Jennifer, Rachael.

I also wish to thank all members of staff and students at the School of Life Sciences for supporting this project and contributing with insightful discussions and advice, each in their own way, in the data collection process.

Thank you Dr. Riccardo Polvara; your enthusiasm, true friendship, loyalty, absolute support, expertise and care proved to me that friends can become family.

To my colleague and fellow PhD office buddy Jamie, thank you for your words of wisdom and encouragement, our endless chats, laughs and cries, your determination in helping me stand for myself and our delightful lunch breaks.

Above all, I owe this PhD to my loving parents, Ms Dora Constantinou and Dr. Christos Constantinou. To the people I look up to no matter how tall I have grown. Thank you for everything. For your endless support, encouragement, sleepless nights, your firm attitude when needed, and for your faith in me and my potential. I would have never come this far without you and I undoubtedly owe everything to you.

I wish to thank my friends and precious nephew and godson for giving me joy and strength in finalising this thesis. I also thank my wonderful grandparents for their unconditional love.

Last but not least, I thank my life partner Prodromos for coming into my life and proving to me that I can achieve whatever I set my mind to. For helping me build myself as a professional, for standing firm in times when I almost gave up, for showing me unconditional love, support, understanding and for believing in me in times when doubt sneaked in.

To the beloved people in my life. Because every day my relationship with them puts me in front of my endless limitations, in front of my desire to learn little by little how to love and be loved. Ευχαριστώ [Thank you]

Abstract

The teaching of undergraduate sciences has long been associated with practical work; an instructional medium through which the teaching of sciences is believed to become effective in terms of promoting conceptual understanding, skill development as well as subject enjoyment. However, empirical evidence on its effectiveness as a teaching method and whether it has any affective value for undergraduates is scarce in the field of Life Sciences, despite claims deeming the practice as one of the costliest aspects of science education. This thesis reports on findings of a mixed-methods case study conducted at a British university to examine the perceived aims of practical work as well as the effectiveness of practical work in conceptual understanding , skill development and impact on affective value for Year 1 and 2.

This research study poses three research questions concerning the effectiveness of practical work in life sciences at a university in England. The first question explores the objectives of practical work as perceived by a representative sample of members of staff in the department of life sciences at the university.The second question examines whether practical tasks effectively enable undergraduates to achieve the intended learning outcomes. Additionally, it investigates the circumstances under which practical tasks are most effective.The third question explores the contribution of practical work towards meaningful learning. Specifically, it assesses the extent to which the affective value of practical work influences meaningful learning and identifies the specific aspects of meaningful learning affected.

Data collection encompassed questionnaires administered to members of staff, laboratory observations and on-the-spot informal assessment of undergraduates' understanding and skill development that provide an objective empirical perspective on how the structuring of practical work lessons can assist in learning. Additionally, findings on undergraduates' questionnaire responses regarding their experiences and expectations in the laboratory before the beginning of the academic year and at the end of their semester along with their future aspirations are reported so as to investigate whether practical work lessons offer opportunities in the cognitive, psychomotor and affective domain for meaningful learning to occur. Laboratory observations revealed specific lesson features of which the importance of providing theoretical scaffolds during experiments so as to help undergraduates in linking theories with observables was prominent. Even though practical work lessons were regarded as effective for developing manipulative skills, the development of conceptual knowledge was not regarded as something that is feasible to materialise in the laboratory, while doing practical work; something aligning with the department's teaching aims. Findings concerning practical work and its contribution in meaningful learning showed that undergraduates , despite being actively engaged within the psychomotor domain and holding positive beliefs towards their experiences in the affective domain, desire more cognitive engagement in the laboratory.

The study suggests that theoretical scaffolds during experiments are vital so as to help undergraduates in linking theories with observables. Additionally, members of staff need to clearly communicate their perceived aims of practical work in order to clarify that there is long-term plan expanding throughout the three years of the degree which embodies a gradual learning process that will allow undergraduates to train, both in technical skills but also in linking theory with observables, and eventually advance to the level they desire. Even though findings indicated that undergraduates who already hold a vision regarding their future plans in science are intrinsically motivated, findings showed that a carefully structured lesson, assistance from professionals , applicability of practical work to real life scenarios as well as a positive environment meeting undergraduates' needs, leads to a positive emotional state which encourages them entering the process of creating meaning, thus attempt to learn meaningfully.

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Chapter 1 Introduction

The learning of sciences has a distinctive characteristic that differentiates it from other subjects: namely, practical work lessons. Practical work as a didactic method has been for a long period, and at times unquestioningly, valued and praised by professionals in both the secondary and tertiary educational sectors, for its implementation in the science and life sciences curricula respectively. Throughout this thesis, the term ‘practical work’ will be used to describe activities taking place in a laboratory where objects and materials are being manipulated and observed (Abrahams, 2011). According to Millar (2002, p. 53), “Practical work seems the natural and right thing to do” when teaching sciences.

The purpose and effectiveness of practical work have been extensively discussed and researched in a considerable amount of secondary education literature (Johnstone, 2001; Watts, 2013). However, its implementation in the science curriculum is costly; furthermore, its role in tertiary education, which is less challenged in the life sciences field than in other branches of science (Seery, 2020; Bennet et al., 2009; Hanif et al., 2008) needs to be clarified, concerning its real benefits in supporting undergraduates’ learning. The literature on tertiary education practical work frequently presents a subjective rhetoric (Martindill & Wilson, 2015) based on the necessity of practical work in the science curriculum, rather than empirical evidence regarding its exact purpose, and whether and to what extent its aims are met (Constantinou & Fotou, 2020).

Almost half a century after Kerr (1963) published the ten aims of practical work in secondary education, findings in the literature have shown that those exact aims, conceptual understanding, development of skills and motivation (Johnstone, 2001; Watts, 2013) still resonate and are equally applicable to tertiary-level sciences (Martindill, 2015). The central distinction between the two educational stages is that in secondary education, the affective value of practical work is prioritised, at least initially, over conceptual understanding. Indeed, the significance of practical work’s purpose has been acknowledged by graduates and practising professionals in sciences, who emphasised the significance of developing technical subject-related skills, compared to the relative insignificance of practical work’s affective value (Boud et al., 1980). This attention to developing subject-related skills could be attributed to undergraduate programmes’ purpose of training undergraduates to join the industry of sciences, rather than creating subject interest and motivation, which are expected to be innate in that stage. Yet, from a teaching perspective, the purpose of practical work has changed over time; it has shifted from solely teaching technical subject-related skills, to becoming more diverse: targeting, amongst other abilities, the better visualisation of scientific theory (Constantinou, 2022; Johnstone, 2001).

With respect to practical work's affective value, undergraduates – in contrast to secondary school students, who are obligated to attend science lessons throughout the course of mandatory school education in the United Kingdom – are expected to be intrinsically motivated to pursue practical work, as it encompasses the core nature of their science-related degree, and is an integral part of their programme. Nevertheless, there has been no empirical research on the affective value of practical work in the life sciences.

Additionally, with practical work being, as advocated, an essential part of science programmes, it is vital to conduct research on how its purpose is perceived by university members of staff who deliver these programmes, since the effectiveness of a programme depends, among other factors, on a clearly structured curriculum. This will potentially allow the enhancement of undergraduates' educational experience and can prepare graduates for a career in science (Oliver et al., 2008).

Although the importance of focusing on training undergraduates in developing their skills has been sufficiently covered in the literature (Kerr, 1963; Khoon, 2004), the promotion of conceptual understanding and its effectiveness have been questioned due to the absence of satisfactory evidence (Boud, 1980; Wang, 2005). Overall, whilst the development of skills has been reported to be effective (Kerr, 1963), it would be unreasonable to assume that the development of science knowledge is a direct 'side effect' of the activity *per se* (Constantinou & Fotou, 2020).

In 1982, Hofstein and Luneta criticised the lack of evidence for the effectiveness of learning in the laboratory; yet two decades later, and after examining new evidence on practical work, they still reported scarce information concerning learning while doing practical work (Hofstein & Luneta, 2004).

However, instead of solely focusing on polar interrogative questions regarding the effectiveness of practical work (stemming from the science education community's dissatisfaction with its place in the curriculum), a small number of recent studies (Galloway, 2015; Seery, 2018) have shifted attention to strategies that could help to clarify "what an effective learning environment might look like" (Seery, 2018, p. 58) and "what laboratory experiences contribute to science learning" (Bretz, 2019, p.193). As Bretz (2019) argues, universities' financial resources are under increased strain, and a reduction of instructional costs is being requested without sacrificing learning quality. Coming from a biomedical sciences background and having participated both as a student studying towards pure sciences undergraduate and graduate degrees as well as a professional in the science industry, "[we] can no longer afford to believe that the importance of teaching laboratories is a truth we hold to be self-evident" (Bretz, 2019, p. 2); nor should it be assumed that there is no need for evidence to support the assertion that undergraduates require, and learn from, hands-on laboratory activities.

As mentioned above, the purpose of practical work in the laboratory has swung in a pendulum-like manner for years, from verification of scientific facts to the Heuristic approach (Armstrong, 1903; Abrahams, 2011); then back to the development of conceptual understanding (Thompson, 1918); and, in 1961, back to the promotion of acquisition of transferable skills and the heuristic approach (Abrahams, 2011). Discussions on the purpose of practical work "despite 200 years [and more] of debate" (Millar, 1987, p. 114), have eventually morphed into a Newton's cradle, swinging almost indefinitely between approaches and ideologies. However, as Schulz (2021) explains,

> *"It is impossible to have an ideal Newton's cradle, because one force will always conspire to slow things to stop: friction. Friction robs the system of energy, slowly bringing the balls to a standstill " (para. 35).*

This 'friction' has become a subject of debate, after decades of practical work, with regard to its high costs, increased hazard awareness, and considerations on how to rightly prepare STEM students for industry (Kelley, 2021). This has brought the science education community to the aforementioned standstill; a moment of truth where research-based evidence was needed to answer the critical question "Does it [science education] have to be hands-on?". Coincidentally published just before the Covid-19 pandemic, Bretz's (2019) question echoes and rightly applies to this study's goal, regarding the purpose of practical work in life sciences:

> *"What evidence does your department have that the significant investment of space, time, personnel, and resources is essential for your students to learn [chemistry]? What arguments and data would your department amass to defend laboratory instruction [...]?" (p. 194).*

Indeed, the Covid-19 pandemic's restrictions, which forced most of the undergraduate population to temporarily implement distant learning and prevented access to laboratories, has provided the science education community with a real-life scenario of teaching sciences without practical work, and its effects in the learning process.

It has become evident that the laboratory, which was regarded as "the very essence of the science learning process" (Abrahams, 2011, p. 9), is now being reconsidered, along with the purpose that it serves in teaching. This, retrospectively, provides the rationale for this research study, which aimed to explore not only the effectiveness of practical work in aiding in conceptual understanding, skill development, and affective value, but also the circumstances under which laboratory work can become effective.

To serve this purpose, this research study, through the conceptual frameworks used, explores 'practical work' as a teaching tool from different perspectives. Perceptions of members of staff, along with observations on how the practical work lessons are designed, delivered and conducted, are compared to laboratory lesson observations and to undergraduates' performance in understanding and skill development. Additionally, undergraduates' perceptions on how they experience practical work, and whether their expectations are being met in the laboratory, give insights into the affective domain, and how this impacts their learning as well as their future aspirations. Lastly, observations concerning the cognitive, psychomotor and affective domains – in the form of conceptual understanding, hands-on experience and psychological impact – allow the examination of whether the three domains observed are integrated in the laboratory, so as to provide the opportunity for meaningful learning to occur (Novak, 2010), as well for maintaining individual interest (Hidi & Renninger, 2006). In other words, this study attempts to examine whether practical work is effective, and to explore ways of enhancing its effectiveness.

The findings of this study are expected to contribute to research concerned with practical work in tertiary sciences, and specifically in the field of life sciences, by providing a more evidence-based approach of how it is being conducted, and how it is perceived by those who deliver it (members of staff), and those who are studying for a degree (undergraduates). Findings are derived from 18 different practical work lessons in the Life Sciences programme offered at the university where this study was conducted; it is hoped that they will contribute to the improvement of teaching in the laboratory, and to provide better learning opportunities for undergraduates. Although the number of lessons observed is relatively small, the incorporation of a case study methodology for each individual lesson allows an in-depth illustration of the main characteristics, issues and patterns relating to the effectiveness and the affective value of practical work, through an examination of different aspects and layers.

This study is divided into six main chapters. After the Introduction (Chapter One), Chapter Two presents a review of the literature, providing a historical retrospection on practical work as a didactical tool; the key large-scale national studies published so far; the purpose of practical work, along with its types and implementation in educational stages, and learning theories underlying it; and an introduction of the three main arguments regarding the rationale for incorporating practical work in the curriculum.

The third chapter concerns the methodology of this research study. It starts with a review of the methods previously used to investigate the topic of interest in the literature; it then discusses emergent issues concerning ethics and the methodologies adopted in the early pilot stages of this research, which later shaped the study. The research focus and strategy follows, presenting the rationale for adopting a case study approach, taking into consideration the validity and reliability factors. In addition to a background introduction describing the setting where the research was conducted and how sample data were collected, the specific research questions are discussed, to demonstrate how this study's objectives are being addressed. Lastly, the theoretical framework, models, and the tools used underlying the former are extensively discussed. The chapter concludes with a discussion on data analysis and approaches used to process the data.

Chapter Four presents key findings, along with their analysis; while Chapter Five addresses the study's research questions, linking the outcomes with the existing literature and suggesting possible explanations and suggestions. The main findings emphasise the importance of lesson design before, during and after experiments, the incorporation of a tripartite model; thinking, feeling, doing; as well as the staff members' role in aiding undergraduates' understanding. The chapter concludes with suggestions deriving from observations on how practical work can be more effective; it also offers recommendations for further research, in order to contribute to the development of knowledge regarding how practical work, as an essential tool for a scientist, can remain in the curriculum, for the right reasons.

Chapter 2 Literature Review

Introduction

Practical work is a didactic tool that has been for a long period, and sometimes unquestioningly, appreciated by teachers and academics for its inclusion in the sciences curriculum in secondary and tertiary education respectively (Sturman et al., 2008; Millar & Abrahams, 2009; Council for Science and Technology, 2013; Velentzas, 2013; Constantinou & Fotou, 2020). Indeed, policy makers worldwide recommend including practical scientific investigation in courses for students of all ages (Jong et al., 2013).

Debates have been taking place within the science education community regarding the status of practical work, in terms of teaching sciences at university level (Osborne, 2015). Although there is a vast amount of literature examining the effectiveness and affective value of practical work in secondary school education, much less has investigated its value within the context of undergraduate science teaching in tertiary education. Similar to secondary schools (Committee on Science and Technology, 2002), universities devote time and effort to planning and conducting practical work; therefore, the relatively large amount of money invested in equipment, staff, supplies, and bureaucratic procedures to ensure ethical clearance and health and safety practices, should be outweighed by the benefits, when compared to classroom-based teaching (Reid & Shah, 2007). Moreover, laboratory work is one of the reasons why tuition fees for international students are considerably higher for degrees in science (BSc, MSc) than arts degrees (BA, MA) (The Complete University Guide, 2018). Indeed, according to Atkins and Brown (2002), practical work is “the most expensive part of a scientist’s education” (p. 92). However, professional bodies, such as the Royal Society of Chemistry, specify a minimum of 300 timetabled laboratory hours as a requirement for bachelor’s degrees (Sanchez, 2022).

Despite the ongoing debate on practical work, schools and universities still carry out practical work without *critically* questioning or justifying its purpose. In terms of such criticality, the following question by Millar (1987) continues to resonate:

> *“But what is this practical work for, and what learning does it promote?”*
>
> *(p. 113)*

Over the years there have been various interpretations of the meaning of ‘practical work’, which is used as an umbrella term used to encapsulate different approaches, such as demonstrations and open research. By undertaking a brief historical survey, it can be seen that the terminology has been swinging in a “pendulum-like manner” (Bennet, 2005, p.75) between different practical-work teaching methods – with a focus on science methodology on the one hand, and on the other, the nature of science (Bennett, 2005). In the past, secondary education practical work started as an instructor-centred activity, for demonstrating and verifying taught theories through practice (Hodson, 1993; National Research Council, 2006). It was not until after the ‘Discovery Learning’ movement, influenced by Bruner (1961), that there was a shift towards learning and acquiring knowledge through experimenting – that is, a more heuristic approach, as introduced by Armstrong (1902). Although the famous mantra “I hear and I forget, I see and I remember, I do and I understand” (Gentry, 1990, p. 9) expressed the principle of the teaching discovery oriented approaches used between 1960s and 1970s, it was soon reconsidered and replaced in the late 1970s by an all-abilities friendly-learning approach; this focused on recipe-like investigative work designed to aid the nurturing of scientific enquiry skills, such as critical observations and hypothesising (Bennett, 2005; National Research Council, 2006).

Whilst the value of practical work is commonly expressed, there is little evidence-based research that it is effective; either in terms of developing conceptual understanding, or its affective value (Abrahams & Millar, 2008, Abrahams, 2009). Although the House of Commons Science and Technology Committee (2002) two decades ago advocated that practical work has an affective value and at the same time contributes to the conceptual understanding of sciences, research evidence showed otherwise. Nevertheless, there seemed to be a slight increase in STEM A-level enrolment, by 0.61% from 2012 to 2017 (BESA, 2017)

Later, the House of Commons contradicted the previous statement, as its findings in 2002 showed that that the number of students choosing to study science further towards an Advanced (A-level) qualification was significantly dropping (House of Commons Science and Technology Committee, 2002). However, in the summer of 2019, almost 70,000 A-levels were awarded in biology (Royal Society of Biology, 2019). Again, in 2020, entry numbers for biology A-levels fell by 6.5%; though one should take into consideration the smaller age 18 population size in comparison to previous years, as well as the cancellation of the summer 2020 exams due to the Covid-19 pandemic (Education Data Lab, 2020).

It should be remembered that higher education science undergraduates have *chosen* that particular field of study – in contrast to students up to the age of 16, for whom, in the UK, science is a compulsory subject. Thus, practical work, which is stereotypically linked to the sciences, might be a motivating factor in undergraduates' studies, given that Abrahams and Millar (2008) found it to be one of the most enjoyable parts of the subject. Additionally, it is believed that practical work assists undergraduates in linking theory with practice through being involved in hands-on activities, since higher education ideally aims to prepare graduates for the science industry with transferable skills. This supports the findings of Gatsby's (2011) study concerning parents' opinions on practical work: they claimed that the use of practical work fulfilled their expectations as to how science should be taught – i.e., with both theory and laboratory work – as it equipped their children with skills needed for working in the science industry.

Opinions on the purpose of practical work in secondary school science vary, with a number of authors holding a pessimistic view on its effectiveness, after finding no link between experimentation and the acquisition of theoretical knowledge with conceptual understanding (Hodson, 1993, 1996; White, 1996; Lunetta et al.2004, Hofstein & Clough, 2007; Abrahams, 2011). Furthermore, the small number of studies on the effectiveness of practical work at university level (DeHaan, 2005; Reid & Shah, 2007; Brownell et al.,; Kloser et al.,2012; Hubbard et al., 2017) makes it difficult to assess the purpose of laboratory activities, even though they are an essential part of the course syllabus.

For this reason, the literature review in this chapter will draw from research in both secondary and tertiary science education (physics, chemistry, biology) that discusses key ideas, in order to identify patterns and differences between the two educational stages. Additionally, it is important to first define the key terms and review the aims and purpose of practical work, along with possible enablers and barriers, from both an effectiveness and affective value perspective. A historical retrospection will provide an insight into how practical work initially emerged, and some seminal national case studies will be discussed. Subsequently, learning theories linked with practical work will be introduced, in order to bring together mechanisms behind learning; this will enable an assessment of whether laboratory work is effective in cultivating the right learning conditions to promote opportunities for effective science learning.

Within this thesis, the terms 'practical work', 'practicals' and 'practical work activities' will be used to describe activities undertaken as part of the science curriculum involving the manipulation and observation of real objects and materials (Osborne & Dillon, 2010), in contrast to virtual ones. Whilst the term 'laboratory work' , 'laboratory lesson' or 'lab work' is frequently used, as Abrahams (2011) noted that much of practical work is student-centred and focuses on what is *done* rather than *where* it is being done; this means that the term ‘practical work’, despite much of it taking place in the laboratory, better describes the activity.

Historical Retrospection on Practical Work in the 20th century

Looking back at the history of science, exclamations such as Archimedes’ famous “Eureka, Eureka” were not made in the laboratory, nor by a scientist in a white coat. Archimedes used his bathroom for studying the hydrostatic laws, thus giving an alternative image to today’s stereotypical idea of empirical scientific knowledge being primarily created in specialised laboratory settings. Interestingly, the earliest evidence of practical work, or learning by doing, takes us back to the discovery of fire about a million years ago – which, according to archaeologists, took place due to *Homo erectus* experimenting with sticks (Gowlett, 2016).

From Archimedes to Galileo and Newton, practical work has been a continuous exploration and observation of the surrounding environment, accompanied by curiosity and continuous systematic investigation; skills that are today embraced by the term ‘scientific method’. Even though the Cambridge dictionary defines a laboratory as a place with scientific equipment, and practical work as a procedure of “working with actions rather than ideas” (Cambridge, 2008

The purpose of the laboratory as part of a chemist’s identity has been partly attributed to historical interventions, as laboratory work became regarded as core in the subject’s curriculum. Von Liebig in the 1830s slowly shifted the pedagogical model, which had included lectures with demonstrations, to one incorporating the laboratory, in order to promote the development of skills and scientific approaches (Seery, 2020). Most schools in England by then regarded practical work as necessary for their curricula; thus, practical work, specifically in chemistry, became incorporated in universities, to teach the skills that were required in industry (Reid & Shah, 2007). Hodson (1990) states that considerable time was invested in repeating practical work to confirm already known results; thus, the education system decided to re-introduce demonstrations. However, Hodson (1993) argues that there was an excessive use of practical work done in the wrong way, which was completely unrelated and had no relevance to their everyday reality.

By the end of the 19th century, the rise of research institutions in science opened pathways to specialisations in the field, thanks to the drive of people doing practical work and learning science out in the real world; this broadened, and created a life-long discipline to work in. Moreover, alternative teaching methods were introduced with the aim of enhancing the effectiveness of practical work in laboratories, such as pre- and post-lab exercises, films and computer simulations (Reid & Shah, 2007).

Concerning the field of biological sciences, the goals and intentions of practical have evolved significantly over the twentieth century, reflecting changes in scientific perspectives, technological breakthroughs, and evolving societal priorities. Naturalists and taxonomists focused their practical work in biology early in the century on the identification and classification of live species (Mayr, 1982). In the 1920s and 1930s, the discovery of genetics and the development of molecular biology resulted in a renewed emphasis on understanding the basic mechanics of life (Watson & Crick, 1953). This resulted in practical work focusing on the structure and function of DNA, RNA, and proteins, as well as the development of novel techniques for manipulating and analysing these molecules.

The use of animal models in practical biology work increased significantly in the mid-twentieth century. This was promoted by technological developments, like the invention of electron microscopy, which enabled detailed imaging of cellular and subcellular components. Animal models have been used to investigate a wide range of biological phenomena, such as embryonic development, disease processes, and the effects of medications and other treatments on living organisms (National Research Council, 1985).

In the second half of the twentieth century, the growth of biotechnology and genetic engineering sparked interest in the modification of DNA (Cohen & Boyer, 1973). During this time period, practical work concentrated on finding new ways for modifying genetic material as well as analysing the ethical consequences of this effort.

The growing connection between biology medicine and pharmacy is one of the key advances in the biosciences sector that has had a substantial impact on practical activity. As a result, a greater emphasis was being placed on the practical application of biological research in the creation of novel medications, therapies, and medical technology (Sampson, 2009). For example, the discovery of the structure of DNA in the 1950s led a new era in medicine development (Ashburn & Thor, 2004). The discovery of molecular biology and the ability to examine the structure and function of proteins and other biological molecules enabled the development of medications that were particularly targeted to certain disease processes.

Initially, practical work in biosciences was often limited to a focus on classifying organisms as well as studying cellular and physiological processes. However, by the mid 20th century practical work shifted to the advancement of technical scientific skills focusing on more sophisticated experimental techniques such as electrophoresis and microscopy (Stent, 1971).Additionally, the introduction of molecular biology in the 1950s and 1960s brought more changes in practical work leading to the teaching of techniques such as DNA sequencing, recombinant DNA technology and gene alterations allowing greater understanding of genetics (Alberts et al.,2014). Moreover, the development of computer technology gave rise to bioinformatics in the 1990s further transforming practical work as computational methods to analyse biological data as well as software programs supporting this area of study were incorporated in the curriculum of universities (Brazas & Fox,2019). In the recent years, ethical considerations have been incorporated in the teaching of the scientific method as it has been growing recognition on its importance (National Research Council, 2004).

Overall, the 20th century saw significant developments in the practical work in the biosciences within university curricula, as new technologies and fields of study emerged. While traditional laboratory exercises remained an important component of scientific education, new methods and approaches were developed to catch up with the changing needs of the field.

What is Practical Work?

Practical work is viewed by a number of educators as an essential part of being a science teacher (Donnely, 1998; Millar, 2009; Abrahams & Saglam, 2010). The Science Community Representing Education (SCORE) stressed practical work's importance by reporting a headteacher's claim that:

> *"Science without practical work is like swimming without water."*
>
> *(SCORE, 2009, p. 11)*

However, when searching the literature for definitions, there appears as yet to be no agreement amongst the science education community on what practical work exactly means (SCORE, 2009). In particular, the National Curriculum has been using a variety of terms, such as practical and enquiry skills, and detailed observation of experimental work (Science in the National Curriculum, 2004), without a specific clarification of definitions. Consequently, the difficulty in clearly identifying the term makes it difficult to apply its objectives in science lessons (Osborne, 2015), and thus the aims of the activity cannot be clear. Hence, Lunetta et al. (2007) recommended a detailed definition that aims to represent practical work in the 19th and 20th centuries:

> *"Learning experiences in which students interact with materials or secondary sources of data to observe and understand the world." (p. 394)*

However, interacting with secondary sources of data would not necessarily allow students to directly manipulate materials; this redirects the definition to include activities taking place during data analysis, which are not referred to as practical work in this study.

For this reason, Millar (2011) presents an alternative definition, which is frequently found in the European science education literature:

> *"Any type of science teaching and learning activity in which students, working either individually or in small groups, are involved in manipulating and/or observing real objects and materials as opposed to virtual objects and materials such as those obtained from a DVD, a computer, simulation or even from a text-based account." (p. 109)*

To obtain a clearer picture of what the umbrella term ‘practical work’ includes, SCORE (2009) asked teachers and stakeholders to fill a multi-actor designed survey, where primary respondents and people related to them were asked to answer questions regarding various activities, and whether they are considered as practical work or not. Educators and stakeholders agreed that investigations and fieldwork were the most representative activities of practical work, along with lab procedures, collecting and analysing data, and planning/designing an investigation. Based on the questionnaire results, it was evident that only the last experimental phase of a science project was regarded as a ‘practical work’ activity, to be followed by the analysis, conclusion and write-up phase. This is verified by the results, since only 26% and 20% of participants agreed that designing and planning, as well as analysing data respectively, were part of the practical work process. Additionally, the high percentage of respondents linking practical work with the laboratory environment may be concerning, due to a possible future overgeneralisation of the term, and the subsequently limited opportunities for activities (perhaps in the physical environment) that might have otherwise been included in the practical work science curriculum.

SCORE (2009, p. 4) defined practical work as a ‘hands-on’ activity that encourages people to think about the world they live in (Woodley, 2009). ‘Scientific techniques and procedures’ along with ‘enquiries and investigations’ are the building blocks that support skill development, and the understanding of everyday phenomena through a scientific lens. Specifically, according to SCORE (2009), scientific techniques and procedures include the ability to apply the health and safety ethic at work, observing and accurately recording measurements, and using equipment while handling living and non-living things. Under the ‘enquiries' subheading, systematic data collection, methodology design and validity, data interpretation and hypothesising and planning are considered the key activities. Complementing individual practical work, demonstrations by qualified staff allow students to focus on questioning what they observe, to model scientific practices, and to observe experiments which can be either complex or hazardous. These core activities enable students to enhance their skills in developing the systematic use of the scientific method.

Regardless of how different authors define practical work, there has been a consensus regarding the way a practical work is undertaken: specifically, through the manipulation or observation of certain objects or events respectively (Millar, 2004; Nuffield, 2018). Therefore, this is the definition that will be used for the purpose of this thesis.

The Purpose of Practical work

From Secondary to Tertiary Education

Even though this research study focuses on practical work in tertiary level Life Sciences, introducing literature on secondary science practical work and its purpose, an area that has been well researched and published, can provide a more comprehensive understanding of science practical work in general as well as part of a broader perspective. This helps in addressing possible gaps or areas that overlap in the literature across the two educational levels. The comparison of aims, methodologies and findings in these two educational levels regarding practical work helps in identifying similarities and differences that will promote understanding on how practical work evolves from secondary to tertiary education, stages that undergraduates have to go through and develop organically.

In this section, literature that pertains to secondary level education will use the term "students", while the literature relating to tertiary level education will use the term "undergraduates".

Teachers in secondary schools invest considerable time in practical work (Abrahams, 2011), believing that it helps in the conceptualisation of scientific knowledge. However, several studies (Woodley, 2009; Abrahams & Reiss, 2012; Abrahams et al., 2013) suggest that practical work is most likely to be effective in developing conceptual understanding if a 'hands-on and minds-on' approach is used to help students link, and recognise, the scientific theories behind the practical work; yet this is very often not the case (Abrahams & Millar, 2008).

A study by Yager et al. (1969) concluded that although there have not yet been any proven improvements in the understanding of science because of practical work, the laboratory teaching approach assisted in the development of laboratory skills. Regarding practical work in secondary education, Shulman and Tamir (1973) found that the goals of science instruction could be achieved with limited laboratory use; consequently, this should raise some major questions as to the true purpose of practical work in the curriculum. Interestingly, even at advanced key stages undergraduates at university level believed that practical work lacks purpose (Reid & Shah, 2007), wastes their time, and replaces teaching hours when they could have been taught substantial new scientific theories. This raises questions about the true purpose of practical work in the curriculum and as a result its role needs to be evaluated as to the benefits it has to offer.

Furthermore, Millar (2009) suggests that one cannot assume that practical work can help students accomplish all the goals of science learning. Such expectations are unrealistic, limiting, and do not, according to Millar, leave much space for thinking how practical work could be used effectively to benefit students. Similarly, Hodson (1993) states that practical work is overly used in the hope of reaching all learning goals; thus, researchers in curricular reforms have been examining this teaching approach in order to improve its value (Hofstein & Lunetta, 1982), putting them in a constant state of chasing the carrot. However, it should be taken into consideration that some countries have minimised or completely excluded practical work from their curriculum (Russel, 2008).

While there have been suggestions for how school teachers could engage students, there has been limited research on the role of the effectiveness and affective value of practical work at university level for life sciences, as well as these activities actual goals and their assessment.

In the case of undergraduate chemistry, laboratory work at university level has been developed to train technicians and industry workers with sufficient skills that enable them to contribute in research and industry (Reid & Shah, 2007; Elliott et al., 2008). However, since not all undergraduates pursue careers as industrial chemists or technicians, the aims of lab work have changed. Most practical work is done to illustrate material being taught in lectures, and it is usually asserted that laboratory work is required because sciences are practical subjects; yet it has been noted that they only enhance students' skills. Institutions invest heavily in equipment, materials, and also trained technicians (Gardner, 1975; Bennet, 2005), in order to provide opportunities for undergraduates to undertake practical work in addition to theoretical teaching therefore clarifications as to its purpose are very well needed. Additionally, at universities, undergraduates specialise in the chosen field of study therefore practical work is focused on the development of advanced techniques, skills and knowledge necessary for the profession in contrast to secondary school practical work lessons where a broad range of introductory topics is covered (Barnett,2012).

While research shows that secondary school students claim practical work as one of their top reasons for liking school science (Abrahams & Millar, 2008; Sharpe, 2012), it has also been found that, contradictory, at a tertiary level undergraduates were not motivated, or enthused, by practical work, as they found the pace of knowledge acquisition too slow compared to lectures (Wills, 1974; Shah, 2004).

Focusing on the possible in-depth reasons why laboratory work might be deemed as lacking affective value for undergraduates, the American Association for Advanced Science highlighted the importance of replacing cookbook-based practical work in undergraduate biology with open, collaborative and inquiry-based research, as this will intellectually engage and motivate students (Volkmann & Abell, 2003; Lott, 2011), while promoting investigation (Brownell et al., 2012). In fact, it was reported that undergraduates who undertook cookbook practicals – similar to the type of work in the majority of universities (Brownell et al., 2012) – lacked motivation and engagement, compared to those who worked in a research-based investigative lab.

Similarly, Trumper (2003) explained that cookbook-based university physics practical work, which leads to obvious, expected results, discourages undergraduates, as it provides them with limited, if any, new information. However, Trumper claimed that even though such practicals are not beneficial, the lack of a laboratory experience would make sciences unappealing. Expanding on the matter, Khoon and Othman (2004) added that practical work should be conducted to let high school students experience physics 'hands-on', even if the goals of laboratory work are not completely fulfilled. However, considering the two previous statements, Millar's (1987) question, "But what is practical work for?" (p. 113) resurfaces, showing that even at university level, as with secondary schools (Abrahams, 2011), practical work is still done without critically considering whether it is the most effective way of achieving its learning objectives. Given that few studies have examined the actual effectiveness of practical work in Life Sciences, Toothacker (1983) for instance claimed that practical work for introductory physics (high-school students aged 16) neither complements traditionally taught material nor helps in the development of skills; this suggests that practical work contributes little to achieving the learning objectives. According to Brown and Atkins (2002), practical work is an expensive activity to implement in a science curriculum; thus, it is important for universities to find ways to make it more effective with minimal cost and time.

Kreitler and Kreitler (1974) argued that the emphasis on practical work in sciences is based on the old 'learn by doing' saying, and reflects a stereotypical image of a 19th-century scientist being a passionate genius, discovering while performing numerous skilful experiments. Similarly, Solomon (1980) reported that many educators believe that "practical work is to science what cooking is to the kitchen (Hofstein et al., 2013 p. 154).

Starting from the beginning, concerning the aims of practical work in secondary school education, Kerr's (1963) study on practical work provided information from teachers in England and Wales. Kerr ranked teachers' opinions on the importance of each practical objective; and a number of other studies followed, pursuing the same objectives.

There has been a broad consensus on the purpose of practical work, principally concerning its use in secondary education, which identifies the following aims:

SECONDARY SCHOOL EDUCATION AIMS FOR PRACTICAL WORK

1. Improve and promote science learning and enhance knowledge to aid comprehension.
2. Foster laboratory and scientific skills (e.g. observations, recording, measuring, using the microscope).
3. Develop scientific thinking (e.g. open-mindedness, observing, critical thinking, problem solving, reasoning).
4. Motivate and enthuse pupils, stimulating their enjoyment.
5. Promote the understanding of the scientific method.
6. Make theories more real through tangible experiments.
7. Application of scientific knowledge to everyday life

(Kerr, 1963; Shulman & Tamir, 1973; Woolnough, 1976; Lynch, 1983; Hodson, 1990; Johnstone & Al-Shuaili, 2001; Hofstein & Lunetta , 2004; Watts, 2013)

In fact, as part of the British National Secondary Curriculum for KS4 (age 14-16) students should develop an understanding of the development of scientific thinking including the power and boundaries of science as well as ethical considerations as they grow in their knowledge of the evolution of scientific thinking. Developing hypotheses, organising experiments, making observations, conducting experiments properly and assessing procedures are all experimental skills and practices that students should master. By presenting observations and other facts, performing mathematical and statistical analyses and presenting logical justifications to their experiments, they should learn to assess and evaluate data using scientific vocabulary, and comprehend the significance of scientific quantities, units and symbols (Department for Education,2014)

However, even though the objectives are similar, there is disagreement with regard to the importance of each objective (Kirschner, 1989). An example is the affective objective and the importance of motivation in practical science, as both Kerr (1963) and Boud et al. (1980) found it to be unimportant, ranked tenth and ninth respectively out of a total of 10 aims (Kirschner, 1989). On the other hand, Woolnough (1976) and Beatty (1982, as cited in Kirschner, 1989) emphasised the importance of the affective domain in practical sessions.

However, Beatty’s study involved elementary school students, which might explain this difference regarding the prioritisation of the aims and purpose of practical work.

At this point, it is important to acknowledge that secondary school provides students with their first laboratory experience, and prepares those who are going to study pure sciences at an undergraduate level. Reid and Shah (2007) stated that in order for practical work to be effective, there should be clear learning objectives and outcomes. Much research has been conducted to investigate the outcomes, since the money and time invested in practical work at university and schools have raised concerns about its actual effectiveness – especially in the United Kingdom, which is one of the most frequent performers of practical work in education, according to the Third International Mathematics and Science Study reports (Bennett, 2003; Parkinson, 2003; TIMSS, 2019).

Tertiary level Education

Having previously discussed about the aims of practical work in secondary level science education as presented in the literature and in national bodies as well as how those aims relate to tertiary level education, it is now time to turn the focus completely on tertiary education in order to review the aims of practical work as discussed in the literature along with the main arguments concerning that. With regard to university laboratories, the purpose of practical work is described in points that are further presented in thematic categories, as follows (Boud et al., 1980; Reid & Shah, 2007; Bruck et al., 2010; Bretz et al., 2013, 2016; George-Williams et al., 2018).

TERTIARY LEVEL UNIVERSITY AIMS FOR PRACTICAL WORK

1. **Skills:**

- Learn and apply skills in different contexts (time management, communication, teamwork, numeracy, problem solving)
- Interpret data
- Describe experiments scientifically
- Become familiar with equipment and apparatus
- Manipulative skills
- Observational skills

- Plan experiments

2. **Scientific Thinking:**
    - Apply and use knowledge in unfamiliar or different contexts
    - Solve problems critically
    - Form hypotheses
    - Design experiments
    - Train students in keeping records of laboratory experiments and writing reports

3. **Improve Science Learning:**
    - Remember and understand the idea behind experiments and apply it to the next ones
    - Illustrate material taught in the lectures
    - Learn science in a more tactile, engaging way
    - Complementing underlying scientific theory

4. **Affective Value:**
    - Instil confidence
    - Build relationships between students and staff
    - Stimulate interest in the subject
    - Provide motivation
    - A feeling of reality for the phenomena talked about in theory

Moreover, in their academic online prospectuses, a number of British universities (Durham, 2018; Leicester, 2018; Manchester, 2018; Nottingham, 2018; York, 2018) have stated the goals of practical work in their science undergraduate programmes, which include:

Skill-related goals

- The promotion of the scientific method
- Equipment handling
- Development of observational, numeracy, technical and motor skills
- Learning how to keep a laboratory book
- Developing critical analysis, problem solving skills
- Learning how to design experiments, identify errors and interpret findings

- Awareness of limitations and accuracy of methods
- Promoting teamwork and collaboration
- Resource management, including consumables and time.
- Independent learning and investigation
- Introducing students to the workforce

Conceptual development goals

- The application of theory to practice, and reinforcement of lecture material

Affective goals

- Motivation towards learning more science and maintaining interest in the subject

The broad expectations and criteria for academic standards in Biosciences within UK higher education have been defined by the QAA (Quality Assurance Agency for Higher Education, 2019) benchmark statements outlining skills and competencies that biosciences graduates should possess. Briefly, undergraduates, in agreement to the aims reviewed in the literature, should be able to use appropriate methods to collect, record, obtain and analyse data as well as develop, plan, conduct and report on investigations. They should also be able to demonstrate fundamental and core experimental skills. Moreover, responsibility, awareness and abiding to ethical regulations was something that undergraduates should familiarise themselves with, something not expected from secondary level students. Graduates in the biosciences must be able to conduct laboratory research on biological systems in a responsible, ethical and safe manner while adhering to health and safety regulations. They ought to be aware of the significance of quality assurance and control, ethical concerns, animal welfare and the effects of investigation on the environment, the organisms being studied, as well as stakeholders involved. Additionally, undergraduates must be able to access and evaluate a range of informational sources, gather and analyse data in the lab, and use appropriate methodologies to prepare, analyse, interpret and present data. Finally, they ought to be able to approach difficulties in the best way possible in the laboratory as part of problem-solving abilities developed.

Indeed, it has been argued that, mostly, the purposes of university practical work incorporate similar themes to those associated with secondary school practical work demonstrating a general initial alignment between the two educational levels (Brown & Atkins, 1988; Kirschner & Meester, 1988; Trumper, 2003; Khoon, 2004; Wang, 2005). If only, secondary education practical work provides the fundamental foundations that tertiary education curricula can build on so as to promote advanced higher order cognitive thinking and skill development. One important difference is that university science, according to the objectives, does not intend to increase (or at least prioritise) the motivation of students. Additionally, undergraduates at universities are usually expected to work more independently and practical work lessons are intended to help them develop their autonomy and take decisions on their own, something valued in a professional career in sciences (Biggs, 2012). Moreover, in tertiary education, practical work lessons ideally should integrate theory and practice as undergraduates already have acquired the fundamentals in biosciences regarding theoretical knowledge and practical work activities aim to give them opportunities to apply that knowledge (Brewer et al.2014). In a survey by Boud et al. (1980), undergraduates, graduates and practising scientists were asked to rank various aims in terms of importance within the context of undergraduate laboratories. Objectives such as practical skills were highly ranked by all respondents, whereas motivation was ranked lowest by graduates and practising scientists. This can be attributed to the fact that laboratory work trains undergraduates to incorporate scientific methods in their routine as future scientists, and helps them to adopt professional attitudes (Brown & Atkins, 1988).

In a study by Bruck and Towns (2013) the goals and priorities of faculty members in different chemistry laboratory courses based on a survey and qualitative research were discussed. Findings demonstrated that faculty members of general chemistry courses place a higher priority on laboratory procedures and equipment than they do on group collaboration, research experience, error analysis and laboratory writing. While physical and analytical chemistry professors, corresponding to advanced modules being taught in the final years of an undergraduate degree, place more emphasis on error analysis and data gathering and analysis, organic chemistry, usually offered early on in the degree curriculum, faculty place more emphasis on each undergraduates' individual technique mastery than on group work and more general communication skills. Less than any other faculty, general chemistry, a prerequisite of organic chemistry being taught in Year 1 of the undergraduate degree, faculty place a lower priority on laboratory writing. There is also a discussion of the difficulties faculty members encounter while instructing courses with big undergraduate enrolments and a variety of majors as well as the requirement for research based data to enhance laboratory curriculum. Additionally, the need for training of teaching assistants is highlighted. The findings suggest that in order to properly prepare undergraduates for their careers , laboratory goals and curriculum need to be reviewed. Particularly, it was not among the highlighted objectives to prepare undergraduates for research. Based on these results, authors anticipated that faculty who were successful in obtaining external funding may have placed a different emphasis on laboratory goals related to research experiences, error analysis and laboratory writing than those who did not. Additionally, faculty discussed the importance of connecting lecture to lab, as undergraduates do not always form a mental connection between the laboratory and the lecture, as there is little evidence supporting the widely held rhetoric that laboratory lessons reinforce conceptual understanding (National Research Council, 2012)

Additionally, another important aspect considered regarding the aims of practical work is student voice directly in order to ensure that there is mutual understanding and agreement between faculty and undergraduates on what the curriculum involves.Mistry and Gorman's study (2020) focused on how undergraduates perceived their laboratory skills in the areas of literacy, health and safety, problem solving, practical skills, practical theory and experimental design at the beginning of their university journey. The results suggest that undergraduates believed that they had good levels of knowledge and experience in handling chemicals properly and collecting experimental data in a laboratory notebook. They were thought to be less skilled in making health and safety evaluations and writing scientific laboratory reports. In terms of undergraduates ability for problem-solving, they rated their ability to seek assistance from laboratory teaching assistants higher than they gave themselves credit for solving their own problems. The performance of specific practical skills such as recrystallisation and distillation procedures were also rated more higher than other practical skills such as thin layer chromatography. According to the study, mastering these abilities while in high school may have the educational benefit of enhancing their experience and confidence. The study also found that undergraduates judgments of their knowledge of practical theory and their abilities for designing experiments were low, stressing the need for activities to help them improve these skills in laboratory courses at university level.

Based on George-Williams' s (2018) study that will be further discussed in more detail at a later following stage, only 23% and 20% of undergraduates respectively, ranked employability and job preparation as important aims of practical work. With a higher percentage in British institutions which place a greater emphasis on developing employability skills, 29% of undergraduates prioritised the development of transferable skills. In later years of undergraduate study, practical and transferable skills begin to take precedence over theoretical understanding. Academic staff and teaching assistants were in agreement with the aims raised by undergraduates, however they emphasised responsibility and safety more. Eventually what was stressed in this study was the necessity of more and improved communication regarding the objectives of practical work. Dekorver and Towns (2016) concur to this as in their investigation of upper level undergraduate chemistry undergraduates' perspectives of practical work goals there was a misalignment between undergraduates' and faculty's goals, something that contributed to the underwhelming outcomes observed in other studies (Hofstein & Lunetta, 2004) of the effects of laboratory coursework on undergraduates' conceptual understanding. Undergraduates in fact focused more on affective goals such as feeling confident about their performance in the laboratory and as a result this led them to adopt behaviours to try and complete experiments on time and achieve high grades. This contradicted the expectations of faculty and to theories on interest and motivation that undergraduates progress through their laboratory coursework in 'auto-pilot' seeking only to fulfil requirements to earn a particular degree (Dekorver and Towns,2016). Moreover, undergraduates frequently lacked meta-cognitive abilities to allow them to self-regulate their learning and as a result monitor their progress towards the goals their instructors aimed them to attain (Dekorver and Towns,2016).

According to Smith (2017), the UK's Department of Innovation and Skills pointed to a high demand for scientists with a good knowledge of, and skill-set within, their field; it announced investment in new programmes that would train science educators to teach effectively. However, Smith (2017) further reports a lack of consensus on skill shortage in science industries, although there is evidence that sciences undergraduates leave university with limited skills for their occupations in STEM industries; this leads them to pursue additional studies in their field, in order to become qualified (Smith, 2017).

Taking that into consideration, Woodin, Carter and Fletcher (2010) called for action for change in Biosciences undergraduate education. The suggestions focused on equipping bioscience undergraduates with a range of competencies and skills including the understanding of the scientific method and its integration in the society, profieciency in communication and teamwork, a fundamental understanding of how to interpret data, and familiarity with modelling, simulation and computational methods. The development of scholarly communities dedicated to efficient methods of teaching and learning should be the objective of biology departments. Additionally, to keep up with current trends in biosciences, undergraduates should also get the chance to engage in real research projects and gain experience with large databases, modelling and simulation.

In fact, the Royal Society of Biology advises that awarding organisations and universities should foster high-quality practical work in biosciences that should encourage problem-solving, group collaboration, observation, measurement and analysis as well as comprehension of the theoretical content. The society further urges the Departments of Business, Innovation, Skills and Education to commit to ensuring consistent and robust funding for infrastructure investments, the provision and replacement of resources and equipment as well as the recruitment and retention of qualified members of staff who must participate in subject specific professional development courses in their field or expertise to be able to prepare well-prepared and qualified scientist graduates for the industry (Royal Society of Biology,2010).

Considering that one of the most commonly stated goals of practical work is to equip secondary school students and undergraduates with a skillset, both manipulative and conceptual, for future employment (Millar, 2004, Reid & Shah, 2007), there is a lack of evidence for its effectiveness. In fact, Hofstein and Lunetta (2004) report that there is a need for more empirical research on the effectiveness of practical work with more rigorous studies that examine the impact of the activity and students' learning outcomes. They suggest that resources are needed to engage undergraduates of different abilities, learning styles and motivational patterns in using approaches for inquiry and justification of claims based on scientific evidence (Hofstein & Lunetta ,2004). Additionally, regarding the suggested and commonly set aim of practical work concerning the conceptual development of undergraduates, Kirschner (1992) argues that learning about sciences is best done by being taught how to do it rather than by actually doing it. Educators mistakenly focus on teaching the process of science rather than using it to learn science. Information presented through avtivities that require problem-solving might overwhelm the working memory. Constructivist pedagogies according to Kirschner et al. (2010) cannot be used effectively until established mental structures have been produved, which is often observed by the third year of undergraduate studies. Kirschner et al. (2006) argues for directed learning in the laboratory as only undergraduates whose science knowledge has advanced to the point where they may effectively use exclusively constructivist techniques, such as problem solving and open inquiry, to scaffold themselves.

Nonetheless, a large amount of the research concerning practical work has been generated for secondary-level education, and Johnstone (2001) has argued that the findings from such research can, usefully, be applied for tertiary-level science education. Hofstein and Lunetta (2004) emphasise the ongoing reform in science education with a focus on the importance of laboratory work and inquiry-based learning. There is a need to rethink the role and practice of laboratory work in science teaching taking into consideration contemporary knowledge about human cognition and learning. There has been a substantial paradigm shift in thinking about the ways learners construct scientific knowledge, and social science research approaches now allow for a more in-depth analysis of lab and classroom procedures. The laboratory is particularly significant at this time, when inquiry is being promoted as a primary method of science teaching and learning (Hofstein and Lunetta, 2004).

According to Hofstein and Lunetta (2004), developments with regard to the aims of practical work in science education now include lab-based science instruction with a focus examining how students learn in that setting as well as engaging students with different abilities, learning styles, motivational patterns and cultural contexts. Aspects that affect effective learning such as attitudes, perceptions, social interaction and cognitive skills should be examined along with learning models, argumentation and scientific reasoning in order to engage students in using inquiry tools to justify their scientific reasoning (Hofstein and Lunetta, 2004). . The objective is to align learning objectives with laboratory activities, paying attention to students' views of their instructors' expectations and aims, the function of laboratory guides, the use of technology, evaluating students' knowledge and skills and taking into account the political dimensions of education linked to the industry needs. Lastly, another objective is to enhance the appropriate training of teachers and as part of their professional development and provide them with sills and resources to successfully teach science in the laboratory (Hofstein and Lunetta, 2004).

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Is Practical Work Effective?

In this section, arguments for the effectiveness of practical work in secondary schools will be examined in relation to specific objectives that are commonly discussed in the literature. These objectives are divided into three main domains: cognitive, affective, psychomotor (skills), which are most commonly associated with the purpose of practical work. Research that investigates the impact of practical work on student learning outcomes in each of these domains will be discussed. Additionally, research on the effectiveness of practical work in tertiary biosciences will be explored and will provide further insight into the role and purpose of practical work in tertiary science education.

Practical Work in Secondary Education

The Cognitive Argument

- **To improve and promote science learning and enhance knowledge**

Wellington (2002) argued that practical work can help students understand science by promoting conceptual development, through tangible experiments that allow students to visualise theoretical concepts. Millar (1989) further explained that actively participating in practical work can help students understand the theoretical ideas behind the task. In contrast, Wellington (2002) proposed that doing science and understanding science are different, since practical tasks can sometimes leave students confused, if done in the wrong way. Whilst some research has claimed that practical work is effective in developing conceptual understanding when tested by pen-and-paper examinations, other studies (Abrahams, 2011; Hodson, 1990; Hodson, 1993) assert the opposite: Sere (1999) and Hirvonen and Viiri (2002) explained that one cannot expect conceptual learning to be a direct “side-effect” (Hirvonen & Viiri, 2002, p. 306) of practical tasks. Nevertheless, Schulz (1994) reported that school practical activities, designed according to the main principles of constructivism, showed a statistically significant improvement in learning, in comparison to outmoded traditional activities.

Karna et al. (2012), as part of the Finnish National Board of Education, examined the effect of certain teaching practices and their impact on students’ scores in the ninth grade of lower secondary school. Their results showed that practical work contributed strongly to the understanding of physics among 2,949 physics students. Tests were based on material from the national curriculum, and students were tested in explaining phenomena and performing an investigation. Success rates of 52%, 57% and 59% in biology, physics and chemistry respectively showed that students performed better when they had to recall information, whereas they encountered difficulties when they were asked to apply and understand the knowledge. However, the results of this study are unusual in the sense that they are rare in the literature, which makes their validity questionable.

Finland was ranked among the top 10 countries in the achievement of science grades at school in 2003 and 2007 (Martin et al., 2012). However, according to Martin et al. (2012), based on the TIMSS 2011 report, Finland was ranked only 16th for the percentage of laboratory resources available in schools, in contrast to England's second place. If Finland had managed to outperform England, a country with a long history of practical work in schools, then investing time and money in this practice is still questionable.

Wellington (2002), Millar (2004) and Abrahams (2008) have argued that practical work does not contribute to the better conceptual understanding of sciences. Indeed, there has been no reported link between students' academic success, in terms of grades, and the hours invested in practical work (Martin, 2012). However, in contrast, Finnish studies (Lavonen & Laaksonen, 2009; Uitto et al., 2012; Karna, 2012) have found that students' performance and academic achievements are impacted by practical work, which allows them to better understand scientific concepts. Curricula in Finland can be developed by schools, which usually practise inquiry-based teaching, following a general structure outlined by the Finnish national curriculum; this may affect the studies' reliability, as they could be biased by the aim of merely trying to promote their country's established curriculum.

Although it has been found that practical work makes theory more realistic (Parkinson, 2003), if guided instruction is absent during an experiment there is a possibility that students become confused and unclear about a topic; hence, they leave the laboratory with misconceptions that could affect their learning (Parkinson, 2003). According to Driver and Bell (1986), students are more likely to see what they want to see in an experiment, rather than what the teacher wants them to see; and preconceived ideas can strongly influence their experience (Roth et al. 1997), if no scaffolding is provided by a more experienced person. Johnstone and Al-SHuaili (2001) found that seeing becomes an observation only when it is interpreted through knowledge. In contrast, Hodson (1996) adopted a Vygotskian perspective to suggest that any type of practical activity, be it student- or teacher-centred, does not prevent students from forming misconceptions, since practical work can also provide erroneous results that need to be interpreted in the right way. This was confirmed by Millar (1998), who explained that expert guidance is needed for students to understand the theory behind their observations. Indeed, it is expected that since students are involved in practical work similar to that undertaken by scientists, their learning will be improved in comparison to other forms of instruction (Domin, 2007).

However, Abrahams and Millar (2008) reported that rather than improving conceptual understanding, practical work was only effective in enabling students to recall information limited to specific details of unusual or memorable (e.g. using the Van de Graaf generator) ‘wizz, bang, pop’ practical work activities. In contrast, Martindill and Wilson (2015) found that pupils aged 13–14 who attended practical lessons could demonstrate conceptual gains, as they could recall more substantial information with scientific explanations from laboratory practice, compared to students who attended a traditional classroom. Furthermore, Martindill and Wilson (2005) suggested that this shows that pupils have a better understanding of the subject. Nonetheless, the difference between the two studies’ outcomes could be attributed to the type of the practical work, since in Martindill’s study, discussion was embedded in the practical session to ensure that students could link theories with observables. On the other hand, in the study by Abrahams and Millar (2008), there was almost no discussion reported, and opportunities for this were not exploited.

In contrast, Atash and Dawson (as cited in Martindill, 2015) reported that students who undertook more practical work achieved lower test results in scientific conceptual understanding than the control group; whereas Mulopo and Fowler (1987) found no difference between students aged 16–17 studying chemistry, when instructed using traditional and practical methods.

Although Hewson and Hewson (1983) reported a significant difference in the understanding of students who have been instructed with practical work and in traditional non-practical instruction, no similar results have duplicated those findings. Furthermore, Shulman and Tamir (1973) noted that over a long period there have been studies aiming to investigate whether practical work and demonstrations are effective in achieving the major purposes of using the laboratory. These purposes included the conceptualisation of complex and abstract matters through manipulation of objects, collection of data so as to emphasise the scientific methodology, and making science enjoyable through practical work. However, based on pen and paper tests, the laboratory has failed to demonstrate any clear advantage (or disadvantage) of practical work, despite its relatively high cost, in terms of developing scientific conceptual knowledge over other methods of teaching (White, 1996; Hodson, 1993; Osborne, 2010).

Additionally, regarding the assessment of conceptual knowledge, apart from the pen-and-paper tests, there has been no evidence that writing a typical post-laboratory report is a proof of conceptual understanding of theories learned during a practical task. This is because the validity of such an assessment is questionable, due to the high probability of erroneous results acquired leading to misconceptions, and invalid conclusions or parroting of the textbook without grasping and understanding a concept (Mathews & McKenna, 2005). Instead of aiming for conceptual understanding, some researchers propose that practical work should focus on providing students with skills, rather than aiding their understanding of scientific knowledge and theories (Hodson, 1993; Trumper, 2003).

Moreover, Bennett (2005) commented and acknowledged that there are other factors, such as the way a practical is planned, or the teaching methodology used, that impact learning much more than practical work *per se*. With respect to the teaching methodologies, Hodson (1996) highlighted the importance of having a theoretical background before entering the laboratory, since students "Do not know where to look, how to look or how to recognise [what they are looking for] when they find it" (Hodson, 1996, p. 118). This way, students can follow the Popperian methodology of testing a hypothesis and introducing the falsification principle (Popper, 1963); they will be able to form a hypothesis upon entering the laboratory, using the hypothetico-deductive model, in order to accept or reject it by the end of their practical work.

Further to Hodson's (1996) suggestion regarding the importance of prerequisite learning before entering the laboratory, Domin (2007) additionally explained that this will support students, as during practical work they experience a "working memory overload" (p. 150), which impedes their learning as there is too much information to be processed in a limited time. Students needs to be actively engaged with the practical while handling equipment, following procedures and manipulating objects; thus, it is difficult for them to simultaneously apply prior knowledge and deal with other materials (Johnstone, 1984). Again, Gunstone and Champagne (as cited in Johnstone & Wham, 1982) suggested that practical work, involving shorter tasks, could leave space for promoting opportunities of conceptual development for the students.

Considering this information overload, Watson et al. (2004) comment that there is a steep learning curve between observing and constructing concepts, since students do not automatically grasp the theory behind the task. Constructivism-based approaches of learning by doing are usually adopted in such studies, and the approach taken to explain the results focuses on the type of practical being undertaken. Hodson (1990) stated, that students cannot learn sciences by using recipes, but instead by doing science like a scientist, being engaged in open, active investigations. As Johnstone (1984) explained, recipe-based laboratory manuals hold a lot of noise as guided instructions include newly introduced information, prompting students to follow the instructions unthinkingly therefore this impedes actual learning and contradicts that practical work, as often practised, contribute in the development of conceptual understanding.

The Skills Argument

- **To foster laboratory and scientific skills (e.g. measuring, using the microscope)**
- **To develop scientific thinking/attitudes (e.g. open-mindedness, observing, critical thinking, problem solving)**
- **To promote the understanding of the scientific method**

Practical work has been considered important for helping students to understand science and to develop certain skills – which, as claimed, can equip them for future employment, either in the science industry or in other occupational fields (Millar, 2004). On the other hand, it has been reported that some STEM graduates do not work in their study fields, but use their degree-related skills in a range of different occupations (Mellors-Bourne et al., 2010). For this reason, the main goal of promoting practical work to enhance the skills of graduates who will follow a science-related degree is questionable, since such some graduates find employment outside their subject area. In addition, employers in general prefer recruiting science graduates, since practical work trains students with skills useful for other roles (Eraut, 2003). Additionally to the acquisition of science-related skills, including handling of equipment and the ability to design and run experiments, practical work has been claimed to foster transferrable skills which can be applied to a broad range of disciplines.

Furthermore, dissenting voices such as those of Parkinson (2003), Bennet (2005), Woodley (2009) and Osborn (2010) questioned the actual development of skills as a result of practical work *per se* Wellington (2002) considered that the implementation of the scientific method promotes qualities that are important for a prospective employer, such as observing, interpreting and problem solving. However, Wellington (2002) challenged those ideas, explaining that being involved in practical work does not necessarily imply subject comprehension, given that a number of students are reluctant to actively engage during experiments, and there has been little evidence of the existence of transferable skills

(Parkinson, 2003). Hodson (1993) noted that the development of skills as general as problem solving and critical thinking, which are not bound to specific subject content, could be developed through a broad range of disciplines, and might actually differ from subject-specific skills required by future scientists (Dawe, 2003; Abrahams, 2005). Even subject-specific skills, Hodson (1993) added, are difficult to obtain, given that students face difficulties in executing straightforward practical tasks, despite being taught science in school laboratories for years (Hodson, 1993). This argument is supported by research evidence from the Assessment of Performance Unit, referring to statistics of 15-year-old students: 89% of them were unable to take correct readings from an ammeter, and less than 15% could perform a basic filtration of copper oxide when preparing copper sulphate (Hodson, 1993). Notwithstanding, Dorell (2014) explained that with regard to science-specific skills, teachers' assessment can be nothing more than subjective: as students are being examined under controlled and topic-bound conditions, it is difficult to discern whether they have successfully understood the methodologies they are practising in the laboratory.

Johnstone and Shuaili (2001) stated that even though handling equipment is an important skill to learn in the laboratory, it is impossible to expect that all machines are the same; this requires re-learning of the apparatus' guidelines every time students come across new equipment. However, difficulties in operating equipment can hinder students from making other observations during experiments, leading to information overload (Johnstone & Al-Shuaili, 2001). Manipulative skills need to be practised systematically so as to become automatic, which allows students to free their attention and focus on observing and interpreting data correctly. In addition, there is a difference between merely seeing something and making observations: a student needs to be in the right mindset conceptually in order to understand what they are seeing, as observation is cognitive and becomes scientific only when bound to relevant theories (Johnstone & Al-Shuaili, 2001). As Hodson (1986) explained, observation depends on background theory; and therefore, observables are perceived in a different way by those undertaking the experiments, meaning that observation skills can be "biased and fallible" (Johnstone & Shuaili, 2001, p. 44). For this reason, assistance from teaching staff is important, as it is not adequate to ask students to observe; they have to be shown how, as well as what, to think while observing (Johnstone & Al-Shuaili, 2001).

Additionally, Wellington (2002) questioned claims attributing the development of scientific attitudes to practical work. He explained that theories do not directly derive from experiments yielding scientifically correct results, nor from experiments that corroborate others' findings. Anomalous data can falsify what has been already known, and it is the scientist's responsibility to critically assess what can be accepted or rejected. For this reason, criticality, as an attribute of the scientific attitude, should not be necessarily viewed as a side effect of practical work, but should be practised during experimentation (Hodson, 1996).

Among other skills, practical work has been claimed to promote teamwork; although research has suggested otherwise, since students usually discuss topics irrelevant to their task when assigned to groups (Parkinson, 2003). Wellington (2002) also found that the cooperative skills developed during group work are highly affected by the dynamics of the team, as more dynamic and confident students might be allocated more duties, leading other members to inadequately commit to the task. Consequently, evidence shows that in an attempt to implement the Wengerian philosophy in practical sessions through the creation of communities of practice, students tend to work in a hierarchical way, leaving difficult tasks to confident students who will be able to get results for the team (Wellington, 2002).

Although Sharpe (2012) found evidence of practical activities nurturing scientific attitudes under teachers' supervision, the transferability of those skills to roles outside the laboratory, based on Gardner and Gould's claims (1990, as cited in Bennet, 2005), remains hopes.

It is evident from the literature that there is no consensus regarding the definition of the word 'skill' (Bennet, 2003; Abrahams & Reiss, 2015). Some authors discuss skills as being tied to the subject studied, whilst others consider them as qualities gained from practical work that can be transferred to different contexts and disciplines (Abrahams & Reiss, 2015). Hofstein and Lunetta (1982) argued that some studies neglect to consider the benefits of process skills or, as Hodson (1990) refers to them, 'content-independent skills' such as observation, predicting, and numeracy skills. Instead, the focus is narrowly placed on the development of practical, or craft, skills that are subject-specific – which would be demonstrated, for instance, by students' ability to build an electric circuit, carry out a cytological staining, handle materials, and work with equipment (Abrahams & Reiss, 2015).

If manipulating materials has been considered to be a purpose of practical work and a direct definition of what the term 'skill' means, then unsurprisingly, traditional class instruction would be regarded as a non-effective method of fostering such skills (Abrahams & Reiss, 2016). Ultimately, if the goal of practical work is related to manipulation of materials, then there are cheaper and less time-consuming ways of achieving that (Abrahams & Reiss, 2016). Millar (1989) claimed that generalisable skills, such as critical thinking and problem solving, are inborn qualities that everyone has the inclination to advance in their lives, irrespective of whether they are studying sciences or another subject. Moreover, according to students, practical work was rated amongst the less effective teaching methods that aided the development of problem-solving skills (Osborne, 1976).

With regard to assessment, one can become competent in a rich variety of practical skills while doing practical work; thus, as Reiss and Abrahams (2015) claim, it is unfeasible to identify whether a student has successfully mastered all of them. However, despite the fact that practical work is at least regarded as a way of developing skills, it appears that the Science National Curriculum in England has been focusing more on assessing conceptual understanding, rather than skills that will allow a student to be competent enough to work in a laboratory (Reiss & Abrahams, 2015). Interestingly, it seems that the curriculum focus and objectives of a school science department has a direct effect on students' abilities upon graduation. Evidence shows that in top PISA (Programme for International Student Assessment) performing countries such as China and Finland, teachers assess practical skills directly, whilst also including a separate mark for practical work performance as part of the examination process (Abrahams et al., 2016).

Reiss and Abrahams (2015) suggested that if schools were to refocus on enhancing actual practical skills, then they should include those in formal examination processes. Welford et al. (1985) stated that practical skills can be assessed indirectly from laboratory reports, given that a write-up requires an understanding of the investigation carried out. However, Abrahams et al. (2013) explained that a direct assessment of practical skills (DAPS) would be more realistic, as students would be able to demonstrate clearly, rather than suggesting through a written piece of work, whether they are capable of applying their practical knowledge while undertaking an experiment in real time. An analogy that could clearly demonstrate the importance of using both IAPS (indirect assessment of practical skills) and DAPS in assessing skills would be the preparation for undertaking a driving test. A candidate needs to demonstrate that they are able to drive on the road (DAPS) whilst also having an understanding of the road traffic rules (or the understanding of the skill) (IAPS) (Abrahams et al., 2016). Indeed, Matthews and McKenna (2005) reported that there is no direct link between the laboratory report assessments and a student's ability to perform an experiment, since a report can be easily copied from a textbook or carry inaccuracies when results are analysed.

Abrahams et al.'s (2015) propose that in secondary education, the over-reliance on IAPS suggests that "teachers tend to focus on mastering only 'minds-on' rather than 'hands-on' *and* 'minds-on' science" (Reiss & Abrahams, 2015, p. 42, italic in original).

Moreover, one of the goals of practical work, and which is regarded as a skill, is to help students develop scientific attitudes. Aiken and Aiken (1969) explained that the profile of a person encompassing a scientific attitude includes a curious mind and a willingness to reject preconceived theories, by replacing them with whatever provides enough evidence to support a case; thus, they develop open-mindedness.

Apart from the meaning previously discussed, the term ‘scientific attitudes’ has been given a polysemic definition, as researchers also use it when discussing the affective value of practical work, and students’ positive attitudes and enjoyment towards learning sciences (Hofstein & Lunetta, 1982; Sharpe, 2012). Consequently, the term ‘scientific attitudes’ will be used in accordance to Hodson’s (1990) definition, meaning that a person applies the mindset qualities of a scientist in different situations.

There has been limited research in the area of developing scientific attitudes in sciences (Hofestein & Lunetta, 1982, Abrahams, 2011), due to the diversity of opinions on the generic qualities a person with scientific attitudes should have. Scientific attitudes have been described briefly as qualities including observability, patience, persistence and meticulousness (Hendry, 1975); whereas researchers such as Lazarowitz and Tamir (1994) proposed an extended list of characteristics, including “honesty, readiness to admit failure, critical assessment of results and limitations, curiosity, risk-taking, objectivity, precision, confidence, perseverance, responsibility, collaboration and readiness to reach consensus” (p. 98).

However, in a study of 274 high school students undertaking biology lessons, honesty and scientific integrity were not always in evidence: during the data collection process, some students with insufficient data, or faulty experiments, ended up copying results from other peers without attribution (Fordham, 1980). These attitudes were a consequence of teachers’ tendencies, and pedagogy that focused primarily on marking reports. Here, a strong emphasis was placed on correct answers, instead of possible explanations and examination of the theories behind the experiment, or its limitations; this approach fails to demonstrate the tentative nature of sciences (Fordham, 1980; Sharpe, 2012).

Furthermore, in addition to scientific attitudes, it has been claimed that practical work promotes the scientific method, so that students can recognise and appreciate the nature of science, which is science as a culture (Hodson, 2009). Even though the scientific method process has been used by scientists in all three pure science disciplines for many decades (Millar, 2009), school laboratories have failed to represent it. This is due to the fact that students mostly engage with ‘recipe style’ experiments, which use neither blind testing, where students engage in open-ended research (Bencze, 1996), nor the hypothetico-deductive model, where pre-hypotheses are formed in order to reject or accept them after the experiment (Millar, 1989).

Millar (2004) explained that although the inductive view of science (where theories are derived from observations) is currently discredited (Abrahams, 2009), as theoretical knowledge is not directly linked to observing, it nevertheless underpins the goals of practical work as a discovery learning process. What the discovery learning assumption does not take into consideration is that observations are theory-laden, and students are influenced by preconceived ideas. In this respect, one of the aims of practical work – namely, to help students construct their own understanding of theories – might be less effective (Millar, 2004) as the learner would be required to be at a certain cognitive development level to support the desired learning outcome (Taber, 2011).

In order for students to understand the scientific method, they need to be aware that experiments are seldomly clear-cut and definite; thus, the distorted view of the experiment-certainty connection (Bencze, 1996) needs to be broken, as the development of theories is not always as easy as is represented in schools. This experiment-certainty has derived from traditional practical work activities that are closely prescribed and do not allow room for planning experiments (Johnstone & Al-Shuaili, 2001).

The Affective Argument

- **To motivate and enthuse pupils, stimulating enjoyment**

“Science education has traditionally paid little attention to the emotions”, and it has been mistakenly asserted that “emotions can safely be left to those who teach the arts and humanities” (Reiss, 2005, p. 17). According to Reiss (2005), ‘affect’ has been used as an umbrella term to include different words, including ‘affect’ and ‘emotions’, which have been used interchangeably and synonymously, and other words such as ‘moods’ and ‘feelings’.

Motivation: Starting with some important definitions for this section, it is necessary to define motivation and its conceptions (intrinsic and extrinsic), along with interest (personal and situational). Educational motivation, according to Palmer (2009), is any action that maintains students’ attention in learning. Interestingly, there have been many definitions proposed for the term ‘intrinsic motivation’. Sansone et al. (2000) defined it as something that occurs when “an activity satisfies basic human needs for competence and control which makes the activity interesting and likely to be performed for its own sake as a means to an end” (p. 445).

Amabile et al. (1986) explained that the characteristics of intrinsic motivation include attention to the actual activity and not the result, willingness to make mistakes, staying resilient, and openly taking risks in order to explore further for the sake of knowledge. In a similar explanation, Shah and Kruglanski (in Sansone et al., 2000) proposed that intrinsic motivation can be defined either as an activity where the content of the goal is key (in terms of substance), or the activity associated with a single goal (in terms of structure). In contrast, Sansone and Smith (in Sansone et al., 2000) defined intrinsic motivation as occurring when someone is motivated to do something out of interest, while multiple goals might be associated with that interest. Lastly, Renninger (in Sansone et al., 2000) viewed the term through a different lens, explaining that intrinsic motivation occurs only when something is associated with individual interest. The researcher in this study will follow Bandura's definition (1986) of motivation being "an inner drive to action" (p. 243), where students, for example, according to Abrahams (2009), manifest this motivation by participating in activities related to science, studying science post-compulsion, etc. Consequently, intrinsic motivation is an inner drive rather than a behaviour that is influenced by an external factor. According to Barkoukis et al. (2008), intrinsic motivation can be related to gaining knowledge, accomplishing a goal, or getting involved in an activity in order to experience stimulating feelings.

Extrinsic motivation, on the other hand, has been defined by Sansone et al. (2000) as "based on something extrinsic to the activity of interest or something extrinsic to the person" (p. 445). Additionally, it is suggested that extrinsic motivation affects the levels of self-determination. Thus, individuals who have enough "self-determined extrinsic motivation" (Sansone et al, 2000, p. 445) can have sufficient levels of motivation to engage with activities that are not intrinsically motivating to them. Hidi (2000) agreed that extrinsic motivation can be extrinsic to the person, and explained that though individuals are interested in the characteristics of the activity, they do it to fulfil their need to gain satisfaction from an external reward, rather than from an activity *per se* that would directly motivate them as a person. Interestingly, motivation is a fluid concept and it is environment-dependent, since it can be affected by extrinsic and intrinsic factors (Barkoukis et al., 2008). For this reason, Bates (2019) points out that people will only be motivated if they understand that they have a need to learn something, believe that they are capable of learning, and prioritise their learning. Without the aforementioned factors, teaching might be futile.

Interest: While interest and intrinsic motivation can sometimes be used synonymously, there are differences in their exact meaning. Bandura (1986) explains that interest is a "fascination in something" (p. 243), whereas "motivation requires an internal drive" (Sharpe, 2012, p. 83). For interest, Abrahams (2009) explains that the term describes a preference for an activity, while this interest is divided into two types: personal and situational. Personal interest, according to Abrahams (2009), concerns personal preference, whereby a person pays more attention, builds resilience and engages for longer. Bergin (1999) stated that emotions and knowledge acquisition can stimulate such personal interest, which can develop gradually. Situational interest, on the other hand, is not as stable and resistant to external influences. As described by Abrahams (2009), situational interest is triggered by a certain situation, or the environment the person is present in (e.g. a memorable event in the laboratory, with a loud noise). However, Schraw et al. (2001) argued that situational interest appears first, and acts as a facilitator of long-term personal interest if maintained. Furthermore, Renninger et al. (2018) added that budling interest impacts learning in a positive way.

Following the same idea, Hidi and Renninger's four-phase model (2006) showed that interest develops through four different stages, where situational interest is triggered, maintained, individual interest emerges, and this results in well-developed personal interest. Triggering, according to Hidi and Baird (1986), initiates interest development; although it might be short-lived, it can lead to maintained interest. This will allow premature interest during an earlier phase, following Hidi and Renninger's model, to become a well-developed phase (Renninger et al., 2018; Rotgans & Schmidt, 2011). The early phases of interest development are characterised by "heightened emotion that emerges during activity […]" (Renninger et al., 2018, p. 3), and reliance on the source of interest provided by a teacher, for example.

According to Weber (2003), learning is related to internal motivation; therefore, to increase that motivation, one should manipulate interest. Schiefele (1991) stated that interest assists the storage of information. Interestingly, interest is viewed by some (Mitchell, 1993; Schiefele, 1991) as a three-dimensional model, consisting of "meaningfulness, impact and competence" (Weber, 2003, p. 377). The meaningfulness of a task allows students to look for the value in it, and the more meaning a task has, the more effort the student will put into completing it. With regard to competence, students are more interested in doing activities they feel capable of performing. As for impact, students are more interested when they feel they are making a difference when completing a task. In a study by Weber (2003), interest was measured using the Learner Empowerment Scale, which was previously reported to be an accurate way of measuring the relationship between interest and internal/external motivation. They indeed found a positive relationship between internal motivation and interest, but not for external motivation. The findings confirmed previous reports asserting that interest can enhance internal motivation (Dwekc, 1986; Shiefele, 1991).

However, if a student who is predisposed to studying sciences is individually interested in science but attends a class that has a very low cognitive demand, they will not remain interested or motivated (Hidi, 2000). Renninger and Hidi (2015) explained that it is the learner who holds responsibility for developing their interest, but it is the association between the individual and their surrounding environment that supports this development.

A study conducted with eight economically challenged students aged 9–12, who enrolled in a summer biology workshop, showed that their interest was triggered by heightened emotion during hands-on activities where they could see and experience phenomena (Renninger and Hidi, 2015) . This effect was not likely to be present in passive activities such as teaching, where students sit and listen. In addition, participants had an increased interest when they could succeed in a challenging situation, due to a sense of accomplishing something. Conversations with their instructor seemed to trigger their interest when they were guided to understand a new concept, whereas interest was less likely to be triggered when their discussion became boring or too difficult to conceptualise. The effectiveness of instructional dialogue as a possible trigger for interest shows to depend heavily on the quality of the scaffolding offered by the instructor, and the instructors working with participants.

By combining motivation and interest, it has been proposed by Renninger and Hidi (2015) that positive feelings affect interest, and as a result motivate people to persist in an activity. In a similar way, worry and negative affective experiences reduce motivation.

Does Practical Work Have an Affective Value?

Researchers have suggested that the importance of practical work lies in its ability to stimulate students' interest in learning sciences (Lazarowitz & Tamir, 1994; Kerr, 1963; Dillon, 2008). As a result, it has been claimed that this interest allows students to be engaged in their practical work tasks, thus allowing them to remember concepts better than when information is taught in a traditional class (Dillon, 2008).

Students have expressed their enthusiasm and enjoyment for practical work (Hofstein et al.,1976; Lazarowitz & Tamir, 1994); however, it is unclear whether students' arguments are valid and unbiased, since their preference might not be related to the worth of practical work as an instructional method, but perhaps as an activity that gives students more freedom during the lesson (Bennet, 2005). Bennet (2005) further explained that students expressed their appreciation for practical work; this is an opportunity for them to collaborate and interact with their peers, as well as allowing them to be in control of their own learning, which allows them to understand concepts at their own pace. Confirming this, it was reported that students' control over an experiment was the reason why they felt motivated (Abrahams, 2009). However, Johnstone and Shuaili (2001) found that there is no guarantee that students will feel motivated just because they are taking part in a practical work task. Rather, they need comprehensible experiments that will allow them to commit to learning while investigating by themselves, although this requires building background knowledge before entering the laboratory (Johnston & Shuaili, 2001). Experiments should not always confirm the expected result, as this is the true nature of the scientific method (Bencze, 1996).

According to Sharpe (2012), the way students express themselves and/or their behaviour with regard to practical work can provide a way to measure its affective value, since it can reveal their attitudes. However, their behaviour alone is sometimes difficult to interpret: for instance, in one case where students were observed to be mostly engaged in discussions, it transpired that their discussion was not related to the task they were undertaking (Hodson, 1993; Dillon, 2008). Consequently, students' claims of being independent during practical sessions are not always beneficial, since they concentrate on non-substantial issues that could possibly be prevented under different conditions, such as a demonstration.

Notably, confirming previous findings by Bennet (2005), students reported their preference for practical work over a conventional lesson, due to the fact that they were not copying information from the board or taking notes while passively listening to their teacher (Martin, 2012). Abrahams (2009) reported that, when asked, students preferred practical lessons due to their distinctive nature and the excitement of handling new equipment or materials. Nevertheless, and unexpectedly for their teachers, students' rate of satisfaction did not increase when more time was invested in practical activities (Hodson, 1993). In addition, Liu (2010) and Hodson (1993) pointed out that the older the students are, the lower their interest and enthusiasm in sciences. In fact, Liu (2010) claimed that older students were feeling uninterested during science lessons, and felt that they were failing due to the subjects' complexity. Abrahams (2009), on the other hand, reported that after Year 7 (12–14 years old), students' liking for practical work was not absolute, and their motivation was more extrinsic rather than intrinsic. In fact, the findings of Abrahams (2009) and Abrahams and Sharpe (2010) showed that whilst teachers frequently used the term 'motivation', what they really meant was 'situational interest'; thus, there was a misrepresentation of the affective value they attributed to practical work.

Various authors (Hidi & Renninger, 2006; Hidi et al., 2000; Abrahams, 2009) have argued that since situational interest does not endure over an extended period, there is a need to re-stimulate this through frequently exposing students to practical activities. However, Abrahams (2009) claimed that due to the fact that students' behaviour could become difficult to manage when switching to a traditional lesson after a practical activity, practical work is a teaching method that "generates non-enduring situational interest rather than any form of enduring motivation towards science as a subject" (Abrahams, 2009, p. 12).

Even when curricula were customised according to the Nuffield organisation's goal of promoting science due to a shortage of scientists, the number of students choosing to study science beyond compulsion did not change (Osborne et al., 2003; Osborne & Collins, 2001; Jenkins, 1994). Abrahams (2009) argued that if there was indeed an affective value in practical work, then students would choose to study science post-compulsion; this would also be reflected in the declining proportion of students pursuing A-level science examinations, implying a possible underlying problem in the way science is being taught (Osborne & Dillon, 2008; Toplis, 2012). Contradictorily, Abrahams and Sharpe (2010) found that there was a 32% increase in students choosing to pursue science after compulsory education; this indicates that some students might be more motivated than others, although this does not inextricably link motivation to more time spent in practical work.

Despite the arguments presented, it should be acknowledged that students' perception of practical lessons could be completely separated from the affective value of the practical work itself, but rather be influenced by other variables such as the way the lesson is structured, the teaching methodology, or students' inability to comprehend concepts that are not applicable to their everyday life (Bennet, 2005). As an example of how the structure of the lesson affects students, it was reported that practical activities were described as enjoyable when they had a clear plan that enabled students to lead the investigation without needing assistance (Watson, as cited in Bennet, 2005). Furthermore, familiarity with the topic made students' experiences more positive, whilst a preference for open-ended practical tasks, despite their difficulty, made the lesson more interesting than follow-the-recipe tasks (Hodson, 1993). Students are discouraged when facing difficulties in correlating observables with theoretical explanations; and teachers, according to Millar (2004), tend to underestimate this obstacle when trying to introduce students to a mindset of finding the correct answer, instead of allowing them to discover and construct their own knowledge that will give them the autonomy the need. Interestingly, this is supported by a survey of 13–16-year-old students, where Hodson (1993) explained that students' motivation decreased when they were presented with difficulties. Unintentionally, the way school practical sessions are structured can affect students' perception of science, as they do not find a reason for doing a task that does not give them expected results; this conveys a distorted idea that a scientist is infallible (Taber, 2017). Consequently, one of the main objectives of practical work in demonstrating the scientific method has failed: teachers believe that a practical approach to the lesson might positively affect the attitudes of students, who as a result expect science to be something that it is not (Taber, 2017).

Students' motivation is highly influenced by their approach to science (Glynn et al., 2007); thus, lesson alterations are needed in order to transform students' perspective on practical tasks. The fact that students are discouraged by the subject as they get older, due to its difficulty, although they are still interested in practical activities (Lazarowitz & Tamir, 1994; Hofstein et al., 1976), indicates that they might feel alienated, since their inability to correctly perform a practical task or understand its scope affects their attitude (Hodson, 1993; Velentzas, 2013). Toplis (2012) and Galloway and Bretz (2015) further suggested that the transition from primary to secondary school gives students high expectations of practical work which are not met, when they realise that the school science curriculum requires the passive learning of information. Students' epistemological maturity was reported to be the reason why practical work could motivate some pupils more than those who were "epistemologically less mature" (Abrahams, 2009, p. 18) and preferred conventional teaching styles (Windschitle & Andre, 1998).

When secondary school teachers were asked to rate motivation as an aim for practical work, they ranked it as the least important for older students (Kerr, 1963). Ndyetabura and Lynch (1983) explained that the only supported goal amongst the affective outcomes of practical work – including personal interest, and encouragement for studying science post-compulsion – was the capability of experiments to make theory more real and tangible (Renner et al., 1985). Denny and Chennell (1986) researched high school students' views on practical work, and found that they considered practical tasks to be activities of confirmatory rather than investigatory nature; thus, they viewed them as similar to a traditional lesson, which they found uninteresting.

Interestingly, White (1996) reported that some studies have found that practical work discouraged students: for instance, in Shepardson and Pizzini's (1993) study, students found problem-solving classroom activities more interesting and fun rather than practical tasks. They further explained that this might be due to the fact that problem-solving activities allow students to take ownership of their own learning, and they plan how to find answers to the questions posed, which actively involves them in the process. However, in some confirmatory laboratory classes, students claimed that they were not sure of what they were expected to learn during the task. Moreover, research by PETA (People for the Ethical Treatment of Animals) (Holden, 1990) reported that practical activities, especially in biological sciences, that involved dissection or animal testing were turning people away from such activities.

Nevertheless, the notion that practical work promotes interest appeared many times in students' interviews (Toplis, 2012), although the type of interest was not distinguished. Abrahams (2008) explained that the interest is situational and is seen as a result of taking part in an alternative (to a traditional class) lesson. However, Toplis (2012) suggested that although the interest might be temporary, at least for secondary school students, it can be seen as an opportunity to take advantage of and trigger students' interest.

Abrahams (2009) concluded that the term 'motivation' has been misused, and what is meant by students' motivation is actually situational. Although teachers want to believe that students' involvement in such activities brings them personal satisfaction, in reality it is just an escape from normal lessons, as students attend a laboratory class that is flexible enough to give them freedom and control over the lesson (Guay, 2000).

According to McCombs et al. (1989), researchers in the psychology and education fields have recognised that learning is an internal process of transforming what is learned into stable and dynamic knowledge. Positive feelings of competency and control can have affective reactions, which contribute to behaviours that allow the student to continue showing resilience and determination, and thus keep learning. Motivation or demotivation of the student's ability to learn is affected by affective variables such as interest or anxiety while learning; this will show the students whether their goals can be realistically met or not.

Novak's theory (2010) explains that thinking, feeling and acting are interrelated and contribute to giving meaning to an experience. Successful learning is more than thinking, since feelings also play a significant role.

> *"Too many students at the school and university level are swimming in a sea of meaninglessness when they should be helped to grasp the meanings of what they are studying and experience the satisfaction and motivation that come with this." (Novak, 2010, p. 38)*

Following from the above quote by Novak (2010), students have emotionally positive and constructive experiences when they understand what they are learning, or they will have emotionally negative experiences when their understanding is unclear.

Learning new concepts (cognitive learning), states of emotions (affective learning) and physical actions (psychomotor learning) enhance a student's ability to have meaningful experiences (Novak, 2010). Positive experiences while learning help students' thinking, ways of feeling and acting. However, the affective component of a learning experience can either enhance or impair learning (Novak, 2010). As Novak further explains, there are some principles that are foundations to meaningful learning. Motivation is a product of the "students' unsatisfied need" (p. 275) to learn something. Feelings and ideas are conceptual filters that the students see their world through; and interestingly, children begin to understand how they feel as early as their first year of life. However, the child begins to develop into an adult that has control over their emotions. Educators usually give instructions about an activity in the class without explaining the rationale; this is a 'parent transaction' where students are being treated like children, and does not empower their needs, as they feel out of control. As Maslow describes, in order for a person to feel satisfied, their needs have to be met and carefully addressed; and when they are not, the adult deviates from an adult emotional posture to that of a child (Novak, 2010).

Practical Work Tertiary Education

Practical work has long been acknowledged to be a fundamental aspect of science education, providing undergraduates with opportunities to develop their conceptual understanding and skills. While there is an abundance of literature on practical work in secondary school science, this has not been the case for practical work in university education and particularly in the life sciences. Despite this, there are numerous practice-based case studies available, and it is important to understand what modern bioscience laboratory education entails. As there is limited literature on practical work in life sciences, researchers have often turned to the literature on chemistry education, where a significant amount of research has been conducted (Seery, Kirk & Agustian, 2019). Even though chemistry and biosciences have some notable distinctions, they also have a lot in common when it comes to fundamental principles and practices in laboratory work. This shared interdisciplinary knowledge, practices, scientific methodologies as well as shared aims regarding the use of practical work as part of the curriculum provides a rationale for the transference of findings from research in practical work in tertiary chemistry education to tertiary biosciences, resources that go beyond traditional disciplinary boundaries.

The Cognitive Argument

Wang (2005) argued that practical work can aid in conceptual development by encouraging undergraduates to visualise theoretical concepts through concrete activities. However, confirming previous studies in secondary education (Wellington,2002; Millar,2004; Abrahams, 2008) Holmes and Wieman (2018) confirmed that there has been no reported link between undergraduates' academic success and the time devoted in practical work. In this study, undergraduates were asked questions related to practical tasks, and others that lacked such content. The researchers initially speculated that since 30% of the physics instructional time was dedicated to practical work, then undergraduates' learning should be boosted by 30%. This study yielded no satisfactory results: there was no benefit attributed to laboratory work enhancing undergraduates' concept knowledge, since undergraduates did not exert mental effort in reasoning and thinking; they were just following instructions in a laboratory manual. However, similarly to what has been found in secondary education (Martindill & Wilson,2005), undergraduates can, with the right type of practical work, have a better understanding of the subject. Domin (2007), reported that expository practical work, where the lecturer provides guidance, had a positive impact for 47% of undergraduates, who showed a preference and believed that this style of lesson helped them understand the subject better. However, Domin's (2007) findings provide non-empirical evidence, as undergraduates' preference enhances the usual rhetoric; that practical work helps them understand better.

With regard to literature concerning the effectiveness of practical work in aiding undergraduates' understanding of science, Brownell et al. (2015) conducted a study that observed course-based undergraduate research, which is practical work structured in such a way to reflect real science research. This allowed undergraduates to discover novel data for themselves, plan their own experiments, collaborate with each other, and engage with the scientific method. In the course, the "QUERY – Question, Experiment, Results, Your interpretation" method (Brownell et al., 2015, p. 4) was used to help undergraduates scaffold the way they think, brainstorm, form hypotheses, explain what happens in their experiment, and interpret results. Although this study did not aim to link results to conceptual understanding, it found that while the difficulty of exams increased with the introduction of this new research-based practical work, the average scores remained constant.

Moreover, Hake (2002) conducted a study on an introductory physics university course, and found a correlation between knowledge gain and active engagement in the lessons. Hake stated that in comparison to undergraduates participating in traditional courses, undergraduates who attended classes with opportunities for active engagement (such as thinking while doing and deciding, and experimentation) had twice as much conceptual gain. When undergraduates were contributing interactively in their own learning, then conceptual development took place. Other studies with college introductory physics undergraduates conducted by Heron et al. (2003) revealed that when they participated in interactive practical work, they could answer questions equally well as those in more senior physics college classes. Meguid and Collins (2017) supported these findings, explaining that student-centred activities stimulate cognitive engagement and understanding, so that they back their statements with socio-constructivist theories. Following a similar pattern, Pukkila (2004) reported that university biology undergraduates' conceptual understanding was affected by being prompted to engage in discussions during teaching, and a priori formulation of hypotheses. Moreover, a call for further research was made, to examine whether inquiry in practical classes would help undergraduates to understand science better. However, at the same time, it was stated that in the short term there was no significant change in undergraduates academic performance in exams. Berg et al. (2003) indicated that open-inquiry practical work in first-year undergraduate chemistry had more positive outcomes than expository sessions, in that undergraduates were better able to reflect on what they practised in the laboratory and could clearly describe, evaluate and troubleshoot objectively.

Similarly, Udovic (2002) stated that cookbook-based practical work did not help undergraduates acquire any skills or gain long-term understanding of the concepts taught. In that study, a lab based course was introduced and compared with traditional non-practical lessons. The difference, again, was that the practical course incorporated the hypothetico-deductive method, allowing them to integrate inquiry and problem-based activities. Undergraduates were tested at the beginning and end of each semester, and the difference between their two tests was calculated in comparison to the undergraduates attending traditional classes. The difference between pre- and post-test scores was much higher for those who attended the practical workshops. However, a possible limitation is that the instructor was different for the two groups, and the lesson outcomes varied, since the workshop was doing practical work and the traditional classes were mostly based on passive lecturing.

Following a literature review, Seymour et al. (2004) reported that out of 54 articles, 83% reported that practical work benefited conceptual understanding; yet the study's methodology did not adequately demonstrate the case, nor the research design used, due to limitations. Kirschner and Meester (1998) identified a belief that in proportion to the time and effort invested in designing and carrying out a practical activity, the knowledge gained is limited compared to other teaching practices. Khoon (2004) further explained that practical work helps undergraduates to experience sciences hands-on. Although the goals for conceptual understanding might not be fully achieved, practical work was acknowledged to work just as efficiently or inefficiently as other learning methodologies (Bennet, 2005).

The Skills Argument

In order for undergraduates to understand science and develop certain technical skill abilities, practical work has been deemed as crucial (Reid & Shah, 2007). These skills are said to prepare undergraduates for future employment, whether it be in the science industry or in other vocational domains. On the other hand, it has been observed that some STEM graduates work in a variety of other occupations while still using their degree-related skills (Mellors-Bourne et al.,2010). For this reason, the main goal of promoting practical work to enhance the skills of graduates who will follow a science-related degree is questionable, since such some graduates find employment outside their subject area. In addition, employers in general prefer recruiting science graduates, since practical work trains students with skills useful for other roles (Eraut, 2003).

At university level, lecturers aim to expose undergraduate to activities where they are required to handle equipment and be involved in processes similar to those in science laboratories, so as to equip them with skills for working in the industry later on (Reid & Shah, 2007). Moreover, Johnstone and Shuaili (2001) stated that even though handling equipment is an important skill to learn in the laboratory, it is impossible to expect that all machines are the same; this requires re-learning of the apparatus' guidelines every time they come across new equipment. However, difficulties in operating equipment can hinder undergraduates from making other observations during experiments, leading to information overload (Johnstone & Al-Shuaili, 2001). Manipulative skills need to be practised systematically so as to become automatic, which allows undergraduates to free their attention and focus on observing and interpreting data correctly. In addition, there is a difference between merely seeing something and making observations: an undergraduate needs to be in the right mindset conceptually in order to understand what they are seeing, as observation is cognitive and becomes scientific only when bound to relevant theories (Johnstone & Al-Shuaili, 2001).

In terms of the development of skills, Holman (cited in Dorell, 2014) reported the concerns being raised by universities regarding prospective undergraduates' qualifications, after a Gatsby Foundation survey found that more than half the staff at 25 universities in the UK believed that undergraduates arrive at university with limited practical skills (Grant & Jenkins, 2011). Kerr's (1963) survey of first-year undergraduate students of all science disciplines revealed that they felt school did not give much attention to "precision, accuracy and estimation of error" (p. 53); and university staff confirmed that even though school provided students with sufficient manipulative skills, there was not enough emphasis on fundamental skills such as time management, health and safety, and objective observation and reporting. Additionally, the Confederation of British Industry (2011) and Reiss et al. (2012) reported the scarcity of scientifically skilled and experienced staff for recruitment in science-related job positions.

Kremmer and Brignel (1990) and Kardash (2000) reported that as a result of practical work there have been improvements in skills such as the ability to orally communicate research findings, and to observe and collect data; but not in the case of formal writing. The skills that appeared to be enhanced in Kardash's study are defined as lower-order skills, and despite an improvement in those basic scientific skills, there is less evidence indicating that practical work can enhance higher-order inquiry skills, such as critical thinking and identifying hypotheses.This is an important point, given that the predominant way of assessing university students' conceptual learning and skills is mostly through write-ups and laboratory notebooks (Bedford et al., 2010). However, Wang and Coll (2005) claimed that assessing laboratory reports can provide, to a certain extent, insights into students' gained practical skills.

Grant (2011) conducted a survey in which undergraduate lab teaching tutors in all three sciences were asked about their perceptions of new undergraduates' laboratory skills. Findings showed that all 34 respondents believed that undergraduates were not well equipped with lab skills, which, as aforementioned, have declined over the years (Smith, 2017); even though university course entry requirements have been raised (Grant, 2011).

Abrahams et al.'s (2015) propose that in secondary education, the over-reliance on indirect assessment of practical skills (IAPS) suggests that "teachers tend to focus on mastering only 'minds-on' rather than 'hands-on' and 'minds-on' science" (Reiss & Abrahams, 2015, p. 42, italic in original).

Indeed, university instructors thought that undergraduates were lacking subject-specific skills such as manual dexterity and manipulating equipment, whereas employers seek candidates with subject independent skills such as team work, critical thinking and common sense (Jackson, 2010).

With regard to the industry's requirements, Jackson (2010) explained that higher education institutions have been delegated as responsible for instructing graduates to acquire skills, since organisations are reluctant to invest time in expensive trainings. Richardson et al. (2012) stated that undergraduates are expected to demonstrate generalisable skills such as error analysis and critical thinking within a year of exposure to practical work in university education. Moreover, the school of physics at the University of Sydney, where the study by Richardson et al. (2012) took place, spends 30 hours on practical work per semester. There was found to be a statistically significant difference between the experimental expertise and sophistication practice chosen by second- and third-year undergraduates, implying that time spent on practical work allows them to consolidate their skills (Richardson et al., 2012). In contrast, although it has been assumed that laboratory experience is followed by competence, Shallcross et al. (2013) argued that time invested in practical activities is not a good indicator of practical skills.

The Affective Argument

Despite being regarded as an objective that is not prioritised in tertiary education based on previous aforementioned findings, researchers suggest that the importance of practical work lies in its ability to promote interest in learning more about the subject (Kerr, 1963). Johnstone and Shuaili (2001) found that there is no guarantee that undergraduates will feel motivated just because they are taking part in a practical work task. Rather, they need comprehensible experiments that will allow them to commit to learning while investigating by themselves, although this requires building background knowledge before entering the laboratory (Johnston & Shuaili, 2001). Despite the fact that undergraduates expressed their excitement when they were "partisan explorers" (Johnston & Shuaili, 2001, p. 47), experiments should not always confirm the expected result , as this is not the true nature of the scientific method (Bencze, 1996).Students' motivation is highly influenced by their approach to science (Glynn et al., 2007); thus, lesson alterations are needed in order to transform students' perspective on practical tasks.

Galloway and Bretz (2015) reported that as undergraduates progressed and transitioned from general chemistry courses to organic chemistry from Year 1 to Year 2, they scored lower in the questionnaire on the affective value, as their expectations of laboratory work were not met.A study by Atiqurrahman et al. (2008) in four Malaysian universities showed that active involvement in practical work had a weak correlation with science interest, although there was a preference for the laboratory environment.

Seymour et al. (2004) reported that undergraduates' motivation for participating in research activities involving practical work is derived from their intrinsic interest in pursuing a career that excites them, rather than a motivation for education per se. However, in terms of motivation for learning, Hodson (1996) and Seymour (2004) claimed that practical work gives undergraduates the impetus for being determined and persisting in finishing their studies. Similarly, studies including Gates et al. (1998) and Humphreys (1997) found that practical research activities at undergraduate level might encourage consideration and interest in pursuing further graduate studies. Additionally, Seymour et al.'s (2004) three-year cohort study showed that undergraduate research experiences clarified and strengthened their intended career direction, whilst helping them to also explore the particular field of science that they wanted to study further. It is interesting to consider that by the time undergraduates start the first year in their chosen degree, they already have an idea of their future goals; hence, they have already been motivated since school to pursue sciences (Emson, 2013). In particular, Emson (2013) found that undergraduates described practical work as fun and enjoyable, in statements that were considered to reveal their interest.Specifically, one student claimed that when the practical activity is enjoyable, they are more keen to learn (Emson, 2013). Nevertheless, Brownell et al.'s (2012) findings show that biology undergraduates' motivation and interest depended on the type of practical, explaining that open-ended research-based practical activities resulted in more positive attitudes, increased self-confidence, and consideration of pursuing and conducting research, compared with students who were following recipe-style practical tasks.

Tertiary education practical work in Biosciences

Although traditional laboratories constitute a physical location with many equipment, chemicals, and other relevant materials, modern laboratories have been reported to starting to become hybrid; physical and virtual. Universities are now embedding virtual labs to enhance undergraduates' conceptual understanding and equip them with the skills needed to succeed in the current labour market. Al-Khalaf (2021) considered virtual labs critical for transforming education and augmenting undergraduates' creative potential. Virtual laboratories and simulation exercises have been reported to have partly replaced certain laboratory classes for teaching bioscience subjects (Celine, Nsanganwimana, & Tarmo, 2022; Dyrberg, Treusch, & Wiegand, 2016) hence, virtual labs, simulation exercises, and non-formal laboratories can, in a sense, characterise modern bioscience laboratory education.

Bioscience laboratory education has been considered as critical for equipping learners with helpful knowledge and skills. Rolfe and Adukwu (2021) consider the capacity of higher learning institutions to deliver updated bioscience knowledge and skills sought by contemporary employers in the context of changing the environmental landscape. They argue that bioscience practical work could help educational institutions equip undergraduates with valuable knowledge and competencies to succeed in today's job market (Rolfe & Adukwu, 2021). Most bioscience programs comprise roughly of 500 hours of practical instruction over three years, integrated into modules and a final-year project (Rolfe & Adukwu, 2021; Coward & Gray, 2014). Practical work can aid instructors equip undergraduates with valuable bioscience skills and foster a conceptual understanding of scientific principles and models (Rolfe & Adukwu, 2021; Miller, Hamel, Holmes, Helmey-Hartman, & Lopatto, 2013). In a study to investigate the effect of an evolutionary genetics experiment on undergraduates' understanding of the course materials, Miller et al. (2013) established that undergraduates' demonstrated positive improvements in comprehending the nature of science and their attitudes toward bioscience.

Bioscience practical work should be more engaging and challenging to equip undergraduates with the desired knowledge, skills, and conceptual understanding. Adams (2009) noted that laboratory work enthuses and stimulates undergraduates through active learning. First-year bioscience practical work has been regarded as a vital and fundamental phase in the development of future bioscientists (Adams, 2009). Instructors should place bioscience practical work in realistic and stimulating contexts to ensure effective learning. Such contexts enable undergraduates to actively learn by engaging in novel research during scheduled laboratory instruction (Adam, 2009). In this regard, open laboratories serve three fundamental functions: providing additional facilities to complete experimental work, enabling undergraduates to seek help to address problems associated with off-campus practical work, and offering audio-tutorial facilities for practical and theoretical work (Adamson & Mercer, 1970). These functions can foster undergraduates' conceptual understanding of bioscience coursework material and gain hands-on skills. Lee, Lai, Yu, and Lin (2012) stated that despite being costly, practical work lessons fostered positive outcomes in affective and cognitive domains. They found that laboratory work enabled undergraduates to write higher-quality laboratory reports, than those by undergraduates not engaged in laboratory work (Lee et al., 2012). Despite these results, the authors suggested the need for curriculum developers to incorporate robust methods to measure and assess laboratory learning outcomes, the role of extensive laboratory work in bioscience learning, and undergraduate learning styles (Lee et al., 2012).

Cann (2014) argued that the growing number of bioscience high school students have increased expectations and limited exposure to practical work before entering higher education, something that makes practical work challenging. Practical work lessons allow undergraduates to acquire and develop critical skills for their chosen discipline, which they could not have adequately acquired by theoretical teaching alone (Cann, 2014; Dohn, Fago, Overgaard, Madsen, & Malte, 2016). Additionally, a positive correlation between self-efficacy in laboratory work and undergraduates' final exam academic performance has been reported (Dohn et al., 2016). Practical work has also been reported to enable undergraduates in understanding complex concepts and physiological processes as the hands-on experiences provide them with "a more concrete idea of the learning content and made the content easier to remember" (Dohn et al., 2016, p.313). Equally, Cann (2014) reported that encouraging practical work enabled undergraduates to develop an in-depth conceptual understanding of course materials and excel in the hands-on aspects of degree programs. The author underlines the value of simple online interventions and pre-lab preparation in increasing undergraduates' engagement with laboratory activities and improving their academic achievement in bioscience courses (Cann, 2014). Research showed that such components of practical work as experimental repetition, collaboration, and data analysis enable undergraduates to think like scientists and thus understand complex concepts (Brownell et al., 2015; Cann, 2014; Constantinou & Fotou, 2020). Course-embedded practical work positively affects the development of undergraduates' understanding and practice of scientific thinking (Brownell et al., 2015). Such practical work enables undergraduates to discover, connect seemingly unconnected phenomena, critically evaluate data sceptically, seek prospects to share their results and communicate with others, and perform practical course-related activities (Brownell et al., 2015). Hence, embedding practical work into bioscience university programs could help equip learners with critical knowledge and skills and enhance their conceptual understanding of course material.

Laboratory work enables university undergraduates to acquire science process skills, such as problem-solving, data interpretation, scientific writing, experimental design, collaborative work, oral communication, and critical analysis. These fundamental skills underpin the conceptual framework of scientific expertise. According to Coil, Wenderoth, Cunningham, and Dirks (2010), laboratory work enables undergraduates to focus on developing skills rather than just understanding the course content. It allows them to develop science process skills that provide the tools and ways of thinking that empower learners to build the robust conceptual frameworks needed to acquire expertise in biosciences (Coil et al., 2010). Similarly, Cooper, Southard, Osness, and Bolger (2022) assert that laboratory work enables undergraduates to participate in authentic science, improves their conceptual understanding, and reinforces the affective aspect of learning. Laboratory work also enhances the capacity of undergraduates to engage in bioscience research and enables instructors to achieve the desired learning outcomes (Corwin, Runyon, Robinson, & Dolan, 2015; Dewey, Evers, & Schuchardt, 2022; Rayment, Moss, Coffey, Kirk, & Sivasubramaniam, 2022; Vlaardingerbroek, Taylor, Bale, & Kennedy, 2017).

However, laboratory practices are often disconnected from current investigations and do not tackle real-life questions that interest learners (Dopico, Linde, & Garcia-Vazquez, 2013; Celine et al., 2022; Wu & O’Dowd, 2013; Whittle & Bickerdike, 2015). Consequently, instructors should design educational lab practices that connect with real-world problems to stimulate learning gains, increase these activities’ affective value, and foster undergraduates’ understanding of undergraduate biology concepts (Dopico et al., 2013). Laboratory work allows undergraduates to practice scientific methodology and initiates them in empirical research and fundamental knowledge (Dopico et al., 2013). Simulations and virtual laboratory activities increase their ability and confidence in operating laboratory equipment and enhance their capacity to engage in classroom discussions (Dyrberg et al., 2016; Wu & O’Dowd, 2013; Vekli & Çalik, 2023). Accordingly, virtual laboratories and simulations can improve their pre-laboratory preparation in natural sciences. Another study demonstrated that plant microtechnique laboratory exercises strengthen undergraduates’ creative thinking skills (Ermayanti, Anwar, & Santri, 2021; Shaffer et al., 2010; Scott et al., 2017; Wu & O’Dowd, 2013; Kirkpatrick, Schuchardt, Baltz, & Cotner, 2018). Laboratory experiments, such as course-based undergraduate research experiences, strengthen their access to authentic scientific opportunities and predict science identity development and perceived prospects to make relevant scientific discoveries (Esparza, Wagler, & Olimpo, 2020l; Hewitt, Bouwma-Gearhart, Kitada, Mason, & Kayes, 2019). These results underline the importance of integrating simple laboratory exercises into bioscience courses to increase their appreciation of course material and enhance their creativity.

Practical work lessons enable undergraduates to accomplish a set of predictable results. Stefani & Tariq (1996) consider undergraduate laboratory work a critical element in enabling undergraduates to accomplish course objectives, enhance conceptual understanding, and increase their knowledge and skills. It enables instructors to connect with the subject in a manner that encourages students to learn, develops students' science dexterity, and enhances students' understanding of the broad principles of developmental biology (Madhuri & Broussard, 2007; Shaffer et al., 2010; Munn, Knuth, Van Horne, Shouse, & Levias, 2017). Munn et al. (2017) found that laboratory experiences enabled undergraduates to develop more sophisticated views regarding the practices and nature of science and have an in-depth appreciation of course concepts. Additionally, Murtonen, Nokkala, and Sodervik (2018) reported that experimental laboratory work enabled undergraduates to understand meiosis and eradicate misconceptions about the subject. It also fostered the learners' metaconceptual awareness of undergraduate biology courses (Murtonen et al., 2018). Experiments also improved undergraduates ability to think scientifically and understand complex biological concepts (Roberts, 2001; Mintzes, Wandersee, & Novak, 2001); increased the conceptual understanding of photosynthesis (Ross, Tronson, & Ritchie, 2006); increased authenticity in science education (Rowland, Pedwell, Lawrie, Lovie-Toon, & Hung, 2016; Stone, 2014); and boosted their theoretical understanding (Scott et al., 2017; Setiono, Rustaman, Rahmat, & Anggraeni, 2017; Shaffer et al., 2010).

The majority of findings presented in the literature demonstrated that laboratory work is essential for developing undergraduates' skills, enabling them to understand complex content material and concepts. However, practical work should be simple and context-based and reflect real-world situations to be appreciated by undergraduates and accomplish their intended objectives.

One of the limitations of the available literature in tertiary bioscience practical work is that some studies are longstanding and may contain outdated information regarding the subject. Other studies are grounded in secondary analysis; thus, findings may contain weak correlations with the subject matter. Despite these limitations, the existing literature provides evidence regarding the benefits of incorporating laboratory exercises into science courses.

Large-scale National Surveys

Historically, only four large-scale national studies have examined teachers' views of practical work in science and its purpose, in England and Wales (Abrahams & Saglam, 2010; Beatty, 1980; Kerr, 1963; Thompson, 1975). This scarcity may be because practical work is often taken for granted, without being adequately questioned regarding its benefits in science teaching (Abrahams, 2011). The earliest study, conducted by Kerr (1963), examined secondary school teachers' perception of practical work by asking them to rank 10 suggested aims based on importance. The next two studies, by Thompson (1975) and Beatty (1980), focused on teachers' attitudes to practical work at Key Stage , a term defined in 1988, 5 (16–18 years old) and 3 (13–14) respectively. Despite the differences in age and subject, the studies found similar results regarding the prioritisation of aims. Among the most important aims of practical work were the following:

- "To encourage accurate observation and description;
- To make scientific phenomena more real;
- To enhance understanding of scientific ideas;
- To arouse and maintain interest;
- To promote a scientific method of thought" (Bennet, 2003, pp. 78–9; Abrahams, 2011, p. 20).

An important outcome of the Kerr (1963) and Thompson (1975) studies was that the teachers' prioritisation of aims was not related to the frequency of use, or to what was happening in reality during practical work classes. Therefore, there were discrepancies between the rhetoric of what teachers claimed they were doing, and actual practice (Abrahams, 2011; Kerr, 1963; Thompson, 1975).

Although four national large-scale studies were conducted, only three of them will be discussed, whose research was conducted with students in Key Stage 5. This level is not compulsory in England and Wales; it prepares students for their A-level examinations, which are the main criterion for admission to UK universities for an undergraduate degree (HMC, 2018). In addition, a study conducted in 2018 by George-Williams and colleagues, which investigated students' and academic staff's perceptions of the aims of undergraduate chemistry practical work, will be introduced and discussed. This is the only recent large-scale study on practical work aims in tertiary education, conducted in two Australian and one British institution. This will further enhance our knowledge of the aims of practical work at universities, and especially institutions in England.

Kerr, 1963

Kerr conducted an extensive seminal research in 1960, involving 701 science teachers, which examined their perceptions on the purpose and nature of practical work in secondary schools in England and Wales (Abrahams, 2005; Kerr, 1963). The methodology of the study had weaknesses, starting from the fact that the schools chosen were selective, including 56% boys' and 26% girls' grammar schools, with only 18% of them being co-educational. Moreover, teachers' perceptions on the purpose of practical work were elicited solely from questionnaires, which according to Abrahams and Millar (2008) and Sharpe (2012) do not provide a pragmatic view of the way practical work is conducted in schools. Secondly, as Kerr (1963) explains, individuals tend to believe that they need to respond in a certain way to meet others' expectations when completing a questionnaire; this can interfere with the research and the acquisition of results representing the reality. In addition, as Holtzhausen (2001) explained, using multiple methods to research a question increases the reliability and validity of results, whilst triangulation of methods can capture a holistic view of the reality, as the "weaknesses of one method will be compensated for by the strengths of the other" (Holtzhausen, 2001, p. 1).

Kerr's findings showed that teachers prioritised different aims based on the students' key stage. As Sharpe (2012) stated, lower-year teachers were focused on maintaining interest in the subject and learning the scientific method (Hodson, 1993). However, Key Stage 5 teachers unanimously agreed in prioritising three aims, and focused on (1) developing skills for accurate observation; (2) recording, clarifying taught theory through practice, and (3) finding principles by investigating. Teachers' ranking of aims can be seen in Table 1, which shows an overall agreement on the aims of practical work across subjects. However, although teachers are generally concerned about covering material for examinations (Abrahams, 2011; Kerr, 1963), as practical work is influenced by the requirements of the examination body's syllabuses (Jenkins, 2002), fitting the requirements of practical examinations has the lowest ranking.

A problematic aspect of the responses and the ranking of those 10 aims is that teachers informed researchers that they had given little thought to their practices (Kerr, 1963). As a result, this raises the question of whether teachers truly believed, and applied, the aforementioned aims in their practices (Abrahams, 2005). Kerr's findings still resonate today: 59 years later, further studies are being published nationally and internationally, which show similarities (Abrahams & Saglam, 2010; Johnstone & Al-Shuaili, 2001; Wellington, 2005).

Table 1

Kerr's ten suggested aims of practical work ranked in order of importance by different teacher subject specialists in Key Stage 5 (age 16–18) (Kerr, 1963, p. 118)

Aims	**Physics**	**Chemistry**	**Biology**
1. To encourage accurate observation and careful recording	1	1	1
2. To promote simple, common-sense, scientific methods of thought	4	4	4
3. To develop manipulative skills	6	5	5
4. To give training in problem solving	8	7	9
5. To fit the requirements of practical examination regulations	10	8	8
6. To elucidate the theoretical work so as to aid comprehension	2	2	2
7. To verify facts and principles already taught	5	6	7
8. To be an integral part of the process of finding facts by investigation and arriving at principles	3	3	3
9. To arouse and maintain interest in the subject	9	10	10
10. To make biological, chemical and physical phenomena more real through actual experience.	7	9	6

Thompson, 1975

Table 2

Thompson's (1975) top six aims of practical work ranked based on their mean scores regarding their importance at Key Stage 5 (age 16–18) in physics, chemistry and biology (Thompson, 1975; Woolnough, 1976)

Aims	**Mean**
1. To encourage accurate observation and description	5.43
2. To make phenomena more real through experience	6.76
3. To promote a logical reasoning method of thought	6.90
4. To develop a critical attitude	7.83
5. To become able to comprehend and carry out instructions	8.90
6. To arouse and maintain interest	8.96

Note: Most important aims have a lower mean rank value (Woolnough, 1976)

A further investigation following Kerr's study was conducted by Thompson (1975), focusing on the purpose of practical work in Key Stage 5 (age 16–18) physics, chemistry and biology. Following the same pattern as the questionnaire developed by Kerr (1963), teachers around England were asked to rank 20 aims of practical work according to importance. With a response rate of over 200 questionnaires per subject specialism, similar to Kerr's sample, the findings demonstrated substantial differences from the previous study.

The acquisition of skills such as observation and description was considered of primary importance, whereas other aims, which had been ranked higher by teachers in Kerr's study, were less prioritised by Thompson's respondents. Noticeable importance was given to "problem solving, arousing and maintaining interest, promoting logical thinking and making phenomena tangible" (Sharpe, 2012; Thompson, 1975).

In Table 2 there is a notable emphasis on maintaining interest in science post-compulsion, as teachers believed that like younger students, sixth formers need to maintain their interest in sciences (Woolnough, 1976) – in contrast with Kerr's findings in Table 1, where the aim is ranked among the least important. This can be explained by a possible change in students' attitudes towards the subject, or by the introduction of the Nuffield courses in 1966, where students were introduced to discovery-learning practical work (Sharpe, 2012).

Importantly, as Woolnough (1976) pointed out, when comparing the aims presented in Thompson's and Kerr's research, the encouragement of accurate observation and description was ranked the highest in both studies. Moreover, Thompson's finding regarding physics, as interpreted by Woolnough (1976), is that practical work was no longer regarded as a means of illustrating theory, but as an exercise for separating the features of theory from practice. Woolnough (1976) also suggested that practical work might have been regarded as a way of developing skills rather than for teaching physics concepts, which thus questions the repeated maxim "[…] I do, and therefore I understand" (Gentry, 1990, p. 9).

It is important to state that during Thompson's study, practical work was shifting from a heuristic discovery-learning approach to the acquisition of skills, given that the former approach applied to a minority of academically able students, and there was a shortage of students studying sciences at a degree level (Gott & Duggan, 1995; Sharpe, 2012). The fact that the actual practical work and students' responses were not taken into consideration, with only teachers' responses collected, does not represent the reality of how a practical lesson takes place in a laboratory (Abrahams & Saglam, 2010).

On this note, Yung (2006) explained that the methodology applied in Thompson's and Kerr's research did not necessarily represent the reality of what was happening, nor the attitudes towards practical work; this is because teachers were provided with, and asked to rate, a list of predetermined aims that did not take into consideration any variations in the subject or the teachers' way of teaching. As Abrahams (2009) explained, there had been no laboratory observations of the actual practices; thus, questionnaires, as mentioned earlier, could only provide the rhetoric, rather the understanding the reasons behind teachers' rankings.

Abrahams & Saglam, 2010

Abrahams and Saglam's study (2010) was conducted using 304 representative schools; it investigated whether there had been changes in the ranking of aims concerning practical work in secondary education across biology, chemistry and physics, by directly comparing results with the original aims used by Kerr (1963). At Key Stage 5, encouragement of accurate observation and recording, along with the promotion of scientific methods of thought, were ranked lower than in Kerr's findings (1963), with the justification that those aims are expected to have been achieved by the time students start their A-levels (Abrahams & Saglam, 2010). The development of manipulative skills was ranked lower by biology and physics teachers, in contrast to teachers in chemistry, one of whom anecdotally stated that the subject requires "higher order manipulative skills" (Abrahams & Saglam, 2010, p. 12). Notably, teachers in Key Stage 5, in comparison to lower key stages and Kerr's results, gave higher rankings to maintaining interest in the subject, and making phenomena real through experience. Some explained that courses as demanding as science courses had to be made more "real and relevant" (Abrahams & Saglam, 2010, p. 12) in order to keep students interested. Abrahams and Saglam (2010) suggested the possibility that the high ranking of those two aims might have been influenced by educational policy makers, and consequently, teachers; this might encourage students to pursue studying sciences at university level, as it has been stated that this would result in positive changes in the economy (Abraham et al., 2018). Abrahams and Saglam (2010) proposed that the aims ranked lower by teachers at Key Stage 5 do not necessarily reflect a lack of importance, but rather an awareness that if the aims are effectively pursued and met at earlier key stage, when they are ranked as more important, they will be expected to subsequently drop (Abrahams, 2011) and different aims will be prioritised later.

George-Williams et al., 2018

This study presented the perceptions of 1,917 undergraduate students, and 152 members of academic staff, on the aims of practical work in undergraduate chemistry courses at all three years of the offered degrees in three institutions (two in Australia and one in the United Kingdom). The most significant aims of practical work that were identified by at least 10% of all year level undergraduates included the theoretical application and enhancement of understanding, the development of practical skills, the acquisition of laboratory experience, preparing for the workforce, and developing transferable skills. The fact that the first five aforementioned aims were acknowledged by more than 10% of students in all three institutions indicated the generalisability of the results among each country and culture. The sixth aim, developing transferable skills, was prioritised by 29% of the undergraduates cohort; this was 17% higher in the British institution, which might be a result of the focused nature of UK degrees. These concentrate on building their students' employability skills that will be required later on in the industry, in compliance with the Dearing report (Dearing & Education, 1997), which required learning to be "increasingly responsive to employment needs" (p. 3). Subtle differences were noticed between the different institutions, as in Australia approximately 49%

of the undergraduates ranked the enhancement of theoretical understanding, most commonly with the development of transferable skills, as the least prominent aim, with 12% of responses.

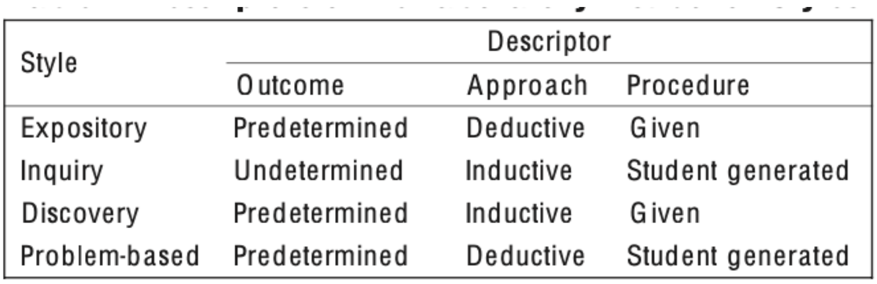
Although employability has been of major importance for universities (Bennett et al., 2015; Boden & Nedeva, 2010), aims related to preparing undergraduates for their careers, along with enhancing laboratory skills, were prioritised by only 20% and 23% undergraduates respectively. Contrastingly, more than 40% of undergraduates at the British institution considered the development of transferrable skills, developing practical skills, and preparing for the workforce to be important. This indicates that the undergraduates at the British institution were focused on long-term goals such as their career, and how certain aims of the laboratory programme could help their introduction to the industry. Among higher-year undergraduates, the enhancement of the theoretical understanding aim decreased in prominence as they progressed, whilst the development of practical skills and transferable skills increased.

Teaching associates were in agreement with the themes raised by undergraduates, while they also regarded the safety and responsibility in the laboratory aim as equally important. Academic staff, being responsible for the design of the programme's curriculum, reported in their interviews that they wanted undergraduates to develop laboratory techniques that they would use in the future, as well as learning scientific concepts in a laboratory setting. They also mentioned the importance of safety and cooperation, which undergraduates would later encounter in their working environment. In agreement with the aims raised by students, the development of practical skills was prominent, along with applying theory to real examples in the laboratory. Interestingly, academic staff did not see the laboratory as an environment where undergraduates could prepare themselves for industry, nor as an opportunity to gain laboratory experience. However, this could be the result of the subtle difference between the aforementioned laboratory work and the development of practical skills, which could imply the latter are necessary for work. Generally, although differences existed between academic staff and students, more communication would be beneficial regarding the aims of practical work.

Types of Practical Work

Table 3

Types of Inquiry (Domin, 1999, p. 543)



Style	Descriptor		
	Outcome	Approach	Procedure
Expository	Predetermined	Deductive	Given
Inquiry	Undetermined	Inductive	Student generated
Discovery	Predetermined	Inductive	Given
Problem-based	Predetermined	Deductive	Student generated

Due to the vast range of aims ascribed to practical work at university level, it would be expected that different instruction forms would exist to support the goals of the lesson (Johnstone & Al-Shuaili, 2001). In order to describe the learning environment in the laboratory, Domin (1999) introduced four different practical work approaches that categorise the forms of inquiry. As presented in the table above, experiments are differentiated by taking into consideration whether their outcome is predetermined or not, whether the methodology is provided or devised by undergraduates, and whether undergraduates follow a deductive learning approach (starting with theory) or an inductive approach (inferring conclusions from data).

The **expository style** practical work lesson is identified more with the cookbook approach, where students follow a protocol in order to complete an experiment, and deduce information from the results that they get, which are already based on a predetermined theoretical framework introduced by the instructor (Seery et al., 2018). Apart from being an easy way to simultaneously engage multiple students, it also requires minimal thinking effort (Domin, 1999), as students are never asked to critically assess the validity of the results; rather, they trustingly compare them against the expected results, which they are usually aware of. This is one of the traditional and most criticised teaching methods (Domin, 1999), as students are not intellectually challenged. This is because the experiment has already been linked with theory, and requires minimal involvement of teaching staff; it also presents a non-realistic view of the scientific method (Domin, 1999), since students are not developing their inquiry skills (Lott, 2011). In contrast, Hofstein and Lunetta (1982) claimed that through inquiry, a skill cultivated in the laboratory, students can develop their conceptual understanding and improve their critical skills. However, Domin (1999) provided two logical explanations for why the expository approach is unable to help students achieve the aforementioned goals. Firstly, students spend their time in aiming to obtain correct results rather than thinking about the process; and secondly, there is not enough time for them to process the experiment and link it with supporting theory, as they are unable to engage in processing prior knowledge or to identify the relevance of their experiment (Domin, 1999).

With regard to the aim of practical work, as Johnstone and Al-Shuaili (2001) explained, the expository style can indeed help students gain manipulative and data-gathering skills, in accordance with the goals of practical work; but it fails to train students in designing an experiment, and students might consider it to be mundane. However, as the authors propose, small modifications can make expository-style experiments more interesting by giving the students freedom – for instance, to compare similarities and differences between two metals when analysing the properties of one of them. Although motivation, stimulating interest and encouraging enjoyment is one of the aims of practical work that teachers pursue in order to please their students, motivation is not guaranteed simply because students are doing a hands-on activity, and expository learning is unlikely to provide excitement since it does not personalise the experience (Johnstone & Al-Shuaili, 2001; Hodson,1 966). Offering little freedom in formulating hypotheses or in designing an experiment leads students to execute a procedure mechanically. Such recipe-like practical activities aim to verify theories presented in books, while failing to give students the experience of the scientific process, since their aim is to investigate “the teacher’s problem and finding the teacher’s answer” (Johnstone & Al-Shuaili, 2001, p. 49).

Structuring experiments in a way that they trigger excitement and encourage self-directed enquiry can motivate students in the long run, and this can be promoted when an activity is relevant to real-life situations (Johnstone & Al-shuaili, 2001). Nevertheless, some practical work lessons focusing on skill development cannot be taught using another approach, since students are required to follow a simple or a complex protocol in order to be trained and develop their skillset (Roberts, 2004). In addition, practical work lessons where students are expected to develop their observation skills, even though they are performed using a cookbook approach, actually train students to develop the conceptual lens they need to use ideas while observing and not just seeing (Roberts, 2004).

The **discovery approach** can be traced back to the heuristic method, introduced by Armstrong (1902), where students had to generate their own hypotheses to test in an experiment. This shares similar characteristics with the expository approach, the only difference being that students are required to infer conclusions from the acquired data in an inductive way, so as to understand the general underlying principles that make their data meaningful: from specific (data), to general (theory). In discovery learning, the teacher helps students throughout the activity so that they discover the expected result. However, as Linn (1977) argued, it is unrealistic to expect students to simultaneously understand a new subject, handle unfamiliar equipment, and use their problem-solving skills to approach a novel situation. For this reason, this approach is not frequently used (Raths et al., 1967); firstly because it is time-consuming, and secondly because the students are supposed to be discoverers who proceed through an experiment with minimal guidance.

Again, according to Domin (1999), this requires more time; and as Hodson (1996) explains, students cannot discover what they have not conceptually understood, assimilated or learned: they "do not know where to look, how to look or how to recognise it when [they] have found it" (p. 118). Dearden (1967) added that something can be discovered or not discovered when students are given the choice to do so. For this reason, and as the outcome is presented by the instructor, Domin (1999) questioned whether this approach actually constitutes discovery learning, since it is not realistic to expect a class of students to report on the same findings.

The **problem-based approach** and **inquiry approach** require students to generate a procedure that they need to follow in order to acquire results. However, a problem-based approach (or guided enquiry), in contrast to the inquiry approach where the outcome is undetermined, has a predetermined outcome and allows students to work with an already defined theoretical framework so as to deduce results. Students must be exposed to the theory and possible experimental methodologies prior to entering the laboratory.

Problem-based instruction allows students to participate in active learning, where the facilitator gives students the necessary material during the lesson, to provide a scaffold for solving a problem. As Johnstone and Al-Shuaili (2001) discussed, the problem must be simple, so as to not overwhelm students conceptually, thereby allowing them to work on the procedure. Students need to work in a cyclical way, rather than a linear process that starts from the identification of a problem and the development of a hypothesis. They should design an experiment so as to answer the research questions, acquire necessary data, and finally interpret the results to derive conclusions that will answer the hypothesis. However, once the student decides on a possible answer, new problems are raised, allowing the student to start a new investigation.

An inquiry approach. on the other hand, is open; outcomes are not determined, and students are therefore required to infer conclusions from their findings, to help them actively engage in relating the experiment to prior knowledge and investigation (Domin, 1999). An inquiry laboratory is best represented by the final-year research project of science students (Johnstone & Al-Shuaili, 2001). Both approaches give students more autonomy in the laboratory, and as a result this improves their attitudes towards science (Ajewole, 1991; Domin, 1999). Yet, in order for students to successfully complete their experiment, they will need to have an understanding of the background knowledge in order to apply it in the laboratory, relate the experiment to previous work, identify a procedure and produce a result – and this is very demanding.

Considering the aforementioned methods, Johnstone and Al-Shuaili (2001) argued that those types of inquiry focus too much on the scientific process rather than knowledge, since students are ideally expected to expose themselves to a real-time authentic scientific investigative experiment. The authors further proposed that an inquiry-based experiment can be used as a short investigation after an expository one, when students would have acquired the fundamentals, in order to reinforce their cognitive development and learning of skills.

Table 4

Description of laboratory instruction approaches adapted from Domin (1991) and Fay et al. (2007).

Types of Inquiry (Domin, 1999)	**Levels of Inquiry (Fay et al., 2007)**	**Question**	**Procedure**	**Solution**	**Predetermined**
Expository	0	Given	Given	Given	Yes
Inquiry (Open Inquiry)	3	Student generated	Student generated	Student generated	No
Discovery	1	Given	Given	Student generated	Yes
Problem-based (Guided inquiry)	2	Given	Student generated	Student generated	Yes

With regard to the components of inquiry, Raths et al. (1986) explained that “hypothesising, explaining, criticising, analysing, judging evidence, inventing and evaluating arguments” (Raths et al., 1986 p.544) are considered as high-order thinking processes – which, as part of the **inquiry approach**, help learners to participate in authentic investigation.

In addition, various factors play an important role in allowing students to mentally engage in an experiment designed to follow the inquiry approach, as suggested by Johnstone and Al-Shuaili (2001):

1. Content knowledge is a vital factor contributing to the effectiveness of an inquiry-structured laboratory lesson. Students should have relevant content knowledge that enables them to suggest possible explanations for results they acquire, which go beyond superficial observation. Furthermore, content knowledge will allow students to develop the right methodological approach, as well as to interpret its effectiveness or limitations, in order to achieve meaningful results. Thus, it is vital for members of staff designing the experiments to have an understanding of the learning prerequisites students should have before entering the laboratory.

2. When students have an input in designing the methodology of an experiment, they become more interested in it. As the outcome depends on the way they designed the experiment, this increases their perseverance. Ownership allows students to be actively involved in the experiment; however, this can only work effectively when students have sufficient conceptual knowledge on their topic.

3. The purpose and the objectives of a practical lesson are vital in giving students a reason for conducting a particular investigation. Often, students wonder why they are doing certain practical activities, what should they be looking at, and how the results should be interpreted. For this reason, being aware of the main objectives and goals of the lesson will allow students to make sense of the activity, and perhaps understand the links between the activity and other complementary modules.

Kirschner (1992) argued against the assumption that scientific knowledge is acquired through methodologies that expose students to experiencing science. Furthermore, Kirschner (1992) added that “[they] confuse the teaching of science as enquiry (a curriculum emphasis on the process of science) and the teaching of science by enquiry (using the process of science to learn science)” (p. 274). While educators try to teach the scientific method that encompasses the habits and reasoning of scientists (Kirkschner, 1992) , they mistakenly immerse students in enquiry approaches with the expectation that they will conceptually understand the scientific process and obtain results just as a professional would (Domin, 1999). Kirschner (1992) argued that if students are not taught how to do something, they are unable to learn it by "acting it out" (Domin, 1999, p. 8). As Anderson (1976) explained, students need to be taught scientific processes, rather than assuming that they will learn the processes on the go by pretending to model a scientist. Undeniably, as Johnstone and Al-Shuaili (2001) explain, if a student has little content knowledge, they will be unable to give an explanation for their results, but merely observe.

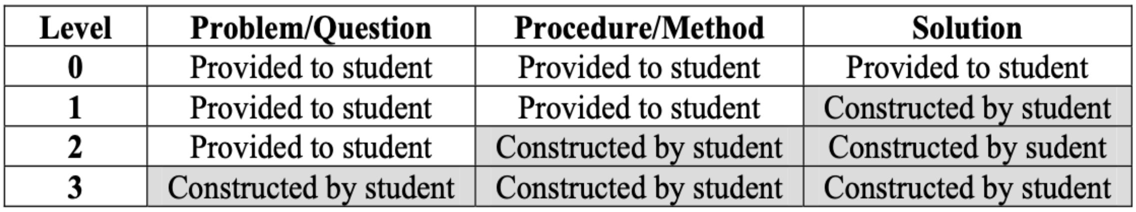
Considering the variety of laboratory instruction approaches, and after conducting a literature review, Domin (1999) claimed that given the lack of a statistically significant cognitive improvement from one learning style over the other, any reports on the effectiveness of a specific instruction style would be surmising. For example, Merritt (1993) had reported that students benefitted from the three non-traditional practical approaches (inquiry, discovery, problem-based), in that they had a better conceptual understanding of scientific concepts, in comparison to practical activities, due to following the expository approach. However, the study lacked a control sample, nor were any ways of assessing conceptual understanding mentioned, apart from student self-reports.

Rubin (1996) worked on a meta-analysis comparing non-conventional approaches (inquiry, discovery, problem-based) with expository approaches in chemistry, physics and geology. The meta-analysis included studies with structured procedures, a control sample, and statistical analysis. Conclusions showed that non-traditional approaches can improve conceptual development in all aforementioned subjects except from chemistry, which showed no significant improvement in learning.

Moreover, Shepardson (1993) reported that students found problem-solving science classes more fun than traditional experiments, as they had more autonomy and freedom to practise on their own, which affected their attitude towards science.

Table 5

Rubric to identify level of inquiry (Fay et al., 2007, p. 215)



Level	Problem/Question	Procedure/Method	Solution
0	Provided to student	Provided to student	Provided to student
1	Provided to student	Provided to student	Constructed by student
2	Provided to student	Constructed by student	Constructed by sudent
3	Constructed by student	Constructed by student	Constructed by student

Fay et al. (2007) took Domin's findings further by exploring the characteristics of inquiry through a rubric that assesses their level (Table 4, Table 5). They identified that the word was used as an umbrella term to describe a range of instructional approaches that were dissimilar, as "there exist shades of inquiry with varying degrees of freedom in the student experience" (Fay et al., 2007, p. 217).

Level 0, according to Seery et al. (2018), is equivalent to the expository approach, where information is provided beforehand, along with the procedure and the solution during the lesson (Xu & Talanquer, 2013). Level 1 relates to a laboratory session where information is being provided at the beginning of the lesson, along with the methodology, but the solution remains to be constructed by the student; this is best represented by the discovery approach. For Level 2, characterised by the problem-based approach, information is provided when requested, and the procedure as well as the solution are left to the students to decide. Level 3 inquiry approaches allow students to choose the research question, the design of the methodology, and the interpretation of the result; this best represents the inquiry approach. With regard to information about procedures, in Level 0 step-by-step guidance is provided, whereas in Level 1 an outline is given. Level 2 requires students to develop a procedure with some guidance.

Practical work will differ based on the guidance provided and what students are expected to do. As Seery et al. (2018) explained, decisions on how the lesson is structured have an impact on the nature of learning. The levels of inquiry rubric allows members of staff to measure this aspect while designing their practical work lessons (Fay et al., 2007). The inquiry levels in the rubric can be used successively, so as to slowly increase students' responsibility during practical work. According to Lott (2011), scientific inquiry can be introduced to students on different levels; but in order for them to advance to a level where they have autonomy and the freedom to work with open inquiry, they must first master scientific skills such as formulating hypotheses, planning their procedure, using equipment and scientific techniques for gathering data, and making informed empirical conclusions.

With regard to empirical studies, Xu and Talanquer's (2013) research focused on exploring the effect that the aforementioned inquiry levels had on students' responses in lab reports in college chemistry. Although the number of the participants recruited in the study was small, findings revealed trends showing that the level of inquiry is correlated with changes in students' reflective statements. Higher levels of experimentation that required students to work autonomously led to less reflections from the students. However, despite the fact that those reflections were not focused on conceptual knowledge and theory, they appeared to emphasise procedural and metacognitive knowledge as students were developing their skills (Xu & Talanquer, 2013). Students who were involved in experiments with higher levels of inquiry could reflect on how to improve the methodological approach, so as to derive to more accurate results.

Russell and Weaver (2011) found that students following a more research-based curriculum (which is included in higher levels of inquiry) developed an understanding and a more sophisticated approach to the scientific method and the nature of science than students using the expository or inquiry-based approach. Students from all the different approaches could explain the scientific process in a similar way, and in the same depth. However, students in the research curriculum could discuss theories related to their experiment, along with their purpose, with more specificity than students in the expository curriculum, where theories and the laboratory activity were discussed much more simply and without any personal experience. In addition, students in the research approach group could describe the experiments from a scientific perspective and could link the activity with their experience. However, even then, students were reporting ideas in "immature ways" (Russel & Weaver, 2011 p. 66), which suggests that they might have been unable to link their experience with scientific processes. Students attending practical work lessons that followed an inquiry approach described their experiment in a similar way to students undertaking expository practical activities, the only difference being the former that they were able to talk about theories using scientifically appropriate ideas. Nevertheless, research-based approaches at higher levels of inquiry gave undergraduates an authentic scientific experience, and they could therefore understand the scientific practice, while also developing their scientific skills; in contrast to students in inquiry and expository practical lessons.

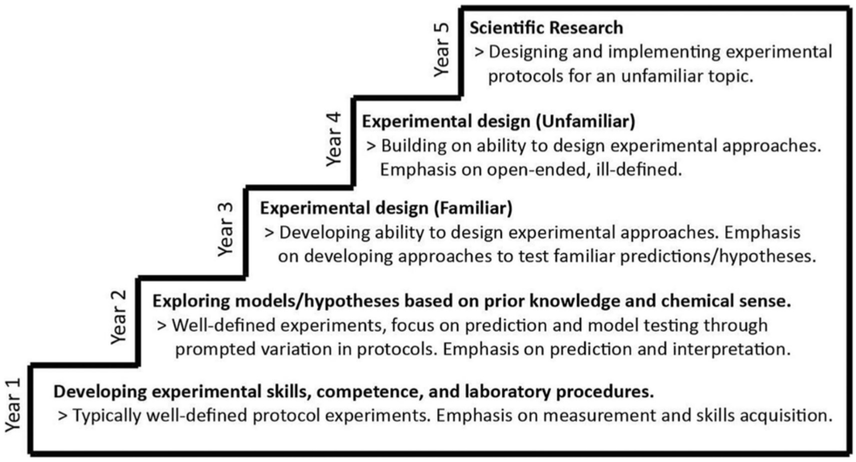
Given that understanding the scientific process and the nature of science is considered one of the main goals of practical work (Hofstein & Lunetta, 2004), it was reported that traditional approaches were not as beneficial as research-based methods and inquiry techniques. In agreement with the aforementioned approaches, Wang (2005) explained that students are expected to understand the meaning of science and being a scientist, so as to be able to work independently rather than following recipes. Learning about the nature of science, developing a "tool kit" (Wang, 2005, p. 644), and building inquiry skills can be achieved through inquiry-based practical work, where students are required to develop the procedure themselves and derive their own interpretations of the outcome.

Stages of Laboratory Activities

Seery et al. (2018) explained that teaching approaches in the laboratory depend on the "overarching principles" (p. 5) and purposes of practical work in the department. One of the aims they explored, and deemed as most important for their department, was training students to do science. Therefore, a model was developed (Figure 1), where different activities were aligned with different results at different stages in their programme's curriculum. Every year "is an iteration more difficult until the final point where students are tasked with designing and implementing protocols for an unfamiliar topic, in their final year project" (p. 6). This aligns with the rubric presented by Fay et al. (2007), where the openness of the practical activity advances with the level of inquiry.

Figure 1

"Curriculum model for developing experimental design, with focus of each stage highlighter" (Seery et al., 2018, p. 6)



In Year 1, according to Seery et al. (2018), the curriculum focuses on the development of skills and building competency in the laboratory; this aligns with Domin's (1999) expository instruction style, and Level 0 inquiry level of the rubric developed by Fay et al. (2007). Criticality is another skill that is intended to be developed through highly structured experiments, where students need to find ways of conducting an experiment and follow the protocol.

In Year 2, as students become increasingly confident and more competent in their work, lecturers can make experiments more complex by introducing higher-order thinking skills such as predicting and explaining, modifying expository practical work accordingly, and allowing students to progressively improve together. A "predict-observe-explain approach" (Seery et al., 2018, p. 6) immediately transforms a cookbook experiment into something more advanced, which fits the students' academic level. Domin's (1999) expository instruction style is modified in such a way that the Level 1 inquiry level of Fay et al. (2007) is introduced.

In Year 3, experimental design with guidance is added,, where undergraduates conduct an experiment following the expository approach first, in order to become familiar with the techniques and data to be collected; then they design an experimental approach, using the skills and ideas required to complete the first part of their traditional experiment. Here, Domin's

(1999) inquiry and discovery approaches can be used, along with Level 2 inquiry (Fay et al., 2007).

In Years 4 and 5, undergraduates are expected to design experimental approaches for unfamiliar situations by working on problem-based projects, and then immerse themselves in research; thereby moving to a problem-based instruction style (Domin, 1999) and Level 3 inquiry (Fay et al., 2007). Seery et al. (2018) concluded that as undergraduates progress to each stage, the outcomes should support the experiences achieved in previous stages.

Following a model similar to Seery et al.'s (2018), where practical work is conducted on different levels based on the level of inquiry, Lott (2011) explained that progression should be done gradually. Whereas in expository-activities, students are given the necessary theoretical background in order to understand the expected outcome, structured inquiry (discovery approach) activities provide everything but the solution, which remains undetermined. If objectives and clues are removed from their laboratory handouts, students can slowly shift from expository to inquiry activities by practising the scientific procedure and the techniques they have learned, so as to form conclusions based on empirical data. Lott (2011) also suggested that for the discovery approach (structured inquiry) to work best, students should do the practical activity before any instruction, but be given an introduction to the topic before the experiment, to explore the concepts themselves. When transitioning from the discovery approach (structured inquiry) to problem-based approach (guided inquiry), students need to practise collecting data in order to formulate conclusions, but also to formulate the procedure. This can only be done if students have the basic theoretical background required to work on the necessary methodological approaches. Moving higher up the ladder of inquiry, in order for students to progress from the problem-based approaches (guided inquiry) to inquiry (open-inquiry), they need to formulate their hypotheses. Before beginning this type of inquiry, students need to have developed their observation skills. Discussion between teachers and students is necessary at this point, to obtain feedback on their observations and hypotheses.

As Lott (2011) claimed, teaching students throughout the levels of inquiry, from expository to inquiry, should be done subtly, slowly and gradually, in order to prepare students accordingly and alleviate stress, instead of using the "jump in to either sink or swim" approach (Lott, 2011, p. 33). Every step gives students more freedom and more control over their practical activities. Even though students might be used to being told what to do (like in cookbook experiments), by slowly building inquiry and technical skills they can move to higher levels of inquiry. Assessment is the determining factor for whether students can move up the ladder of inquiry levels.

Learning through Practical Work: Before, during & After

Relevant theories

By this point, context and background knowledge about the main arguments concerning practical work and its effectiveness in various domains (conceptual, skill, affective) should have provided a comprehensive overview of what has been discussed in the literature on the subject. The discussion of existing literature aided in the identification of gaps and allowed for the establishment of a solid foundation for better appreciating the relevance and implications of theories underlying this study. The effectiveness of practical work is discussed below through the lens of various theories that have emerged while reviewing the literature and will help to explain how practical work can be effective, providing a better understanding of the research problem. Discussing the theories in light of the existing literature allows readers to explain how the relevant theories chosen evolved during the literature review process and how they aided in the design of the study, as presented in the Methodology chapter. Finally, theories that were prominent throughout the review are examined, reconsidered, and discussed in their modern form, as reported in the literature.

Through the Lens of Cognitive Load Theory

The effectiveness of practical work has been argued to be affected by the way information is presented to undergraduates. Practical work has been argued to have a significant cognitive load, as the laboratory is considered as a complex and demanding learning environment due to the multiplicity of interdependent factors involved (Agustian & Seery, 2017). Cognitive load theory (Sweller et al., 1988) is concerned with the amount of cognitive effort exerted in a learning situation, and suggests that the cognitive load has an impact on the working memory, which has limited capacity (Agustian & Seery, 2017) for auditory and visual information (Van der Zee et al., 2017). Flooding it can result in “working memory overload” (Domin, 2017, p. 150) and problematic information retention (Van der Zee et al., 2017). Cognitive overload occurs when great mental effort due to demand is placed on the working memory, resulting from the rapid introduction of a large amount of unfamiliar information or the expectation that students will process information quickly in a limited amount of time (Abrahams, 2011; Tamir, 1991).

Cognitive load, according to Sweller (1988), appears as part of a triarchic model, consisting of intrinsic load, extraneous load, and germane load. Intrinsic load is related to the level of difficulty to the information exposed (Agustian & Seery, 2017) and depends on the learner's level of expertise (Debue & Van de Leemput, 2014), as more experienced students are better able to arrange information in already organised schemata, which limits the risk of overwhelming the working memory (Debue & Van de Leemput, 2014). Extraneous load is related to the way information is presented and instructed, as difficulty in extracting information from supportive material can inhibit learning (Agustian & Seery, 2017; Debue & Van de Leemput, 2014). Finally, germane load refers to the learning processes by which a learner can incorporate information in their long-term memory by automatising schemata (Debue & Van de Leemput, 2014).

Complementary materials that aim to support students' learning, if they are not already embedded in their learning process, will challenge them the most in situations where they cannot be accessed when a difficulty is encountered. When the learner encounters difficulties during a task they are working on (intrinsic load), in combination with experiencing cognitive load when trying to integrate newly introduced information from supportive material (extraneous load), then this high load leads to unsatisfactory learning (Agustian & Seery, 2017). For the reduction of cognitive 'noise', according to Johnstone and Wham (1982), literature on pre-laboratory activities has been attempting to examine how supporting material can be embedded in the learning process in a way that reduces the cognitive load that can potentially overwhelm students, when they experience novel situations and newly introduced information during their experiments (Johnstone & Al-Shuaili, 2001).

Pre-Laboratory

Referring back to cognitive load theory, intrinsic load is reported to be reduced when learners have background knowledge on what they are learning in class, given that familiar information already organised as a schema in the working memory allows the easier processing of similar information (EIP, 2016), something contributing to an effective practical work lesson. For many years, the default activity preceding laboratory work has been a pre-laboratory lecture, held at the beginning of the practical work lesson: this presents relevant theoretical knowledge underlying the experiment to be performed, as well as a discussion of laboratory procedures (Agustian & Seery, 2017). The fact that university laboratory classes are now larger in size, and therefore host more students, has made it less feasible for timetabling to accommodate corresponding lectures prior to practical work classes. This has led to changes in the curriculum, with the need to treat practical work as a stand-alone lesson (Agustian & Seery, 2017) rather than being directly complementary to lectures. For this reason, published literature mainly focuses on ways of presenting students with material on scientific concepts they will encounter in the laboratory, as a way of preparing them prior to entering the laboratory setting.

Findings from studies such as that of Kirk and Layman (1996) showed that students using pre-laboratory guidelines in order to connect practical work with material taught in lectures, felt better prepared for their experiment, as well as understanding concepts and processes more clearly. Apart from pre-lecture material, studies have reported on the use of quizzes with a minimum score requirement in general and organic chemistry, to ensure that students were, in a sense, forced to complete the required work before entering the laboratory (Chittleborough et al., 2007; Kolodny & Bayly, 1983; Starkey & Kieper, 1983). Students explained that active feedback automatically directed them to relevant reading material, and offered guidance towards the correct answers, which required them to become prepared in advance.

Another approach reported was the facilitation of pre-laboratory discussions that aimed to introduce students to the problem to be resolved in advance, so as to use that information in the laboratory while working cooperatively in problem-based experiments (Domin, 2007). In fact, students reported that they felt more cognitively engaged, in comparison to expository laboratories (Agustian & Seery, 2017). However, it was reported that presenting information through problem-solving activities, which are usually minimally guided, puts extra load on the working memory (extraneous load), as students are focused on finding a solution to the problem faced (Kirschner et al., 2006). Nevertheless, Sweller et al., (1998) suggested that goal-free problems, similar to expository activities, can avoid the problem of engaging in high processing means-end analysis. Similar results concerning the improvement of conceptual understanding in the laboratory while doing practical work were presented in other studies (Davidowitz et al., 2003), with students reporting that pre-laboratory discussions, apart from preparing them in understanding their experiments for the forthcoming lesson, helped them in linking pre-laboratory and post-laboratory work for their analysis (Agustian & Seery, 2017; Limniou et al., 2009; Kolodny & Bayly, 1983; Johnstone et al., 1994); they also encouraged minds-on activity during their experiment (Harrison, 2017). Furthermore, pre-laboratory activities, including argumentation construction (Chen & She, 2012), follow the Popperian methodology (Hattie & Donoghue,2016) and encourage the formation of hypotheses before entering the laboratory as part of the hypothetico-deductive model, in order to accept or reject them as a means of deriving a conclusion after the experiment finishes.

Similar to conceptual development, research has also focused on preparing students in terms of technical skills as part of a pre-laboratory activity. Quizzes were also used in testing technical skills knowledge (Starkey & Kieper, 1983). Additionally, simulations enabled students to experiment with procedures they would encounter in the laboratory in advance (Agustian & Seery, 2017). In a study where students needed to complete a simulation activity and achieve 70% prior to being allowed to attend the inorganic chemistry laboratory, they were reported to have attempted this multiple times, until they achieved a score closer to 100% (Nichols, 1999). In another study where students used simulations to prepare for a practical work class in pH, it was reported that they asked more refined theoretical questions than the control group (Winberg & Berg, 2007).

Lastly, another approach that prepared students for laboratory work was the use of technical skill-related videos. Video demonstrations were used to support laboratory teaching, which resulted in members of staff intervening less in comparison to lessons prior to the use of videos (Simpson, 1973; Watson, 1977), and less scaffolding being required (Powell & Mason, 2013). The use of pre-laboratory videos was reported to increase post-test laboratory scores in comparison to those who did not watch the videos, and these students completed their experiments more quickly (Nadelson et al., 2015). Furthermore, providing students with videos prior to their laboratory work in inorganic and organic chemistry, using the flipped teaching model, reportedly helped students by clarifying laboratory procedures and making them feel more comfortable with the underlying conceptual theory (Teo et al., 2014).

In-Laboratory

Even though findings emerging from the literature show that practical work's impact on conceptual understanding is limited deeming the activity, at best, as no more effective than any other teaching strategies (Hofstein and Lunetta,1982, Bennet,2005) there has been research in university education showing otherwise. What those research studies had in common (Hake,2002; Heron,2003;Pukkila,2004) was that they could structure the practical tasks in such a way where the focus was centred around students aiding them to learn from practical tasks with techniques based on constructivism principles. However, as Seymour et al. (2004) reported, out of 54 articles where 83% reported benefits in conceptual understanding after practical work, the methodology had limitations making it hard to demonstrate the case and interpret substantial gains. Constructivism according to Taber (2011), unfortunately, has developed into a broadly used slogan that is being applied in diverse ways and contexts. Due to the fact that constructivism in the science education community has been considered, as Taber (2011) states, as the accepted paradigm for learning, an exploration of the different lenses through which this learning theory is understood is going to be discussed. Constructivism, both as traditionally discussed and with its current modern redefinitions explains how practical work can be effective, answering the main research questions, based on how undergraduates learn.

Constructivism redefined: From Piaget and Vygotsky, to Neuroconstructivism and Human constructivism

Constructivism is a learning theory associated with the branch of cognitive psychology, stating that students do not learn passively but instead create their own learning from experiences and interactions in their effort to gain awareness of their environment (Forrester et al.,2001; Schunk,2012). Every learner has a subjective interpretation of the objective reality therefore constructs knowledge differently thus requires a student-teacher interaction as part of an active learning process (Richardson, 2007). Jean Piaget and Lev Vygotsky' theories on cognitive constructivism and social constructivism respectively have greatly influenced teaching approaches. Piaget proposed that specific mind structures, schemata represent the individual's reflections on their environment and the foundations of their knowledge (Waring, 2006). These schemata are considered as building blocks of thinking (Woolfolk,2011). Schemata develop and become more organised as thinking matures and becomes more logical, complex and sophisticated (Schunk,2012). Learners always seek internal cognitive stability (Schunk,2012) therefore when pre-existing schemata are not aligned with new experiences, perturbation arises leading to cognitive conflict that consequently drives learners to seek equilibration and reestablishment of balance. If the new experience cannot be fitted or assimilated in an already existing schema (Woolfolk,2011; Schunk, 2012) then a new schema will need to be developed so as for the learner to fit this new information that will match their external reality with their internal perception through the process of accommodation (Snowman, 2011). However, sometimes the learner ignores accommodation and assimilation when getting into a knowledge rupture by facing something unfamiliar. As a result, information might be distorted in order to make it fit to previously assimilated material that already fits in their schemata (Woolfolk,2011).

Piaget, as interpreted by Duncan (1995) regarded sociocultural stimuli such as the role of the teacher or peers, as extrinsic influences that disturb the learner's internal mental processes in order to create cognitive conflict and trigger equilibration. Vygotsky believed that the social environment aids learners in developing their capabilities while actively participating in it (Waring, 2006). Cultural development manifests itself first upon interactions with others -inter-psychologically- when knowledge is constructed through shared activities. The internalisation of experiences and acquired skills emerges intra-psychologically as it becomes part of the learner's cognition for future use. (Waring, 2006; Woolfolk, 2011)

According to Vygotsky's sociocultural theory, language supports thinking and reasoning (Woolfolk, 2011) and helps learners to develop intellectually through language-based assistance from more knowledgeable others and is thus a key component of cognition that contributes in development. Furthermore, Vygotsky believed that learners should not rediscover knowledge that already exists in their culture should seek expert guidance order to learn it effectively (Woolfolk,2011).

This guidance takes place in the zone of proximal development where learners experience cognitive changes while interacting with more knowledgeable peers (Schunk,2012). Sanders (2005) defines the zone of proximal development as the distance between what a learner can achieve on their own and their potential development while being supervised by a more experienced person. Learning in this Vygotskian principle of the zone is gradual. First students are assisted by more capable individuals to achieve self-regulation. Slowly, the expert hand-over control to students who can direct their learning. Once knowledge is internalised, students no longer require assistance until de-automisation where what was learned is no longer available which relegates them to early stages of the zone. (Sanders, 2005) Scaffolding during collaborative learning in the zone involves providing information and encouraging students to internalise learning. (Woolfolk, 2011) Scaffolding can include expert feedback, encouraging students to think aloud and clarify their arguments and ideas (Sanders, 2005). As a result, scaffolds are gradually removed until assistance is no longer needed, allowing students to do more by themselves (Sanders, 2005).

Even though Piaget focused on the subject interacting alone with the environment, Vygotsky focused on the social aspect of learners living in a communities that influence learning obtained from the culture in which social interactions take place (Vygotsky, 1978). In fact, Vygotsky (2012) explained that we learn about academic or scientific concepts from others as scientific concepts are not automatically available to the learner and cannot be copied from one mind to another. Vygotsky argued that meaningful learning can only take place when teaching goes beyond what is already known but is within reach of existing understanding. To exemplify, the zone of proximal development is not of a standard size but is individually dependent. Additionally, the Zone of Proximal development is relevant to classroom peers as learners with similar zones can input within the zones of others. For most students, considerable input is required in the classroom (Taber, 2011), though the greater their motivation and metacognitive skills the easier the teaching becomes.

While constructivism, at some level, implies that the learner should be solely responsible for constructing their learning with minimal teacher guidance (Hobbis,2018), Kirschner et al. (2010) states that this is not efficient. In contrast, constructivist paeadgogies cannot be effectively applied, at least not until a established schemata are properly developed (Hobbis,2018). Established schemata usually become apparent in the third year. At this point students are well trained to think scientifically, relate observations to theory and develop their skills. Guidance, scaffolding and feedback are still necessary for undergraduates based on research findings demonstrating evidence against the use of purely unguided experiential learning (Kirschner et al., 2010). Even though discovering individually can have a motivational value (Taber, 2011), the learning environment needs to be designed in a specific way to make important aspects discoverable, the teacher needs to scaffold the learner within their Zone of Proximal Development. From a constructivism perspective, learners missing observations obvious to the teacher is expected as perceptions dependent on existing conceptual views and scientific ideas are counter-intuitive (Taber,2011). Constructivism is usually associated with teaching based on modelling scientific research, which is not very effective in teaching core topics, but is preferred for teaching skills and the method of enquiry (Taber, 2011). Teaching based on constructivism, as Taber suggests, needs to provide the “database for learning” (p.57) and guide but not overwhelm the process of learners’ reflecting on their experiences as only when the learner recognises a discrepancy between expected ideas and experience, will the internal process of modifying those ideas be triggered.

> *" The aim of constructivist teaching then is not to provide 'direct' instruction, or 'minimal' instruction, but optimum levels of instruction. […] Constructivism as a learning theory suggests that effective teaching needs to be both student-centred and teacher-directed" (Taber, 2011 p.57)*

Neuroconstructivism

> *" Constructivism is a major referent in education, although it has been understood in various ways, including as a learning theory; a philosophical stance on human knowledge; and an approach to social enquiry. "*
>
> *(Taber, 2011 p.1)*

Hobbiss |(2018) explains that constructivism is functional but problematic upon certain interpretations as "it is a theory of learning not a theory of pedagogy" (para.1). Neuroconstructivism as a theory of cognitive neuroscience (Mareschal et al.,2007) uses evidence to support the theory but challenges the pedagogical approach the way it is frequently applied in the educational sector.

A key feature of neuroconstructivism is that the way information is stored in the brain is context-dependent and reflects the environment in which it is constructed. Humans are able to construct partial representations, based on neuroconstructivism terminology, which capture the features of the environment in which the information was originally stored (Hobbiss,2018). Assuming that constructivism as a learning theory implies a pedagogical approach is deemed problematic (Hobbiss, 2018) as constructivism places the onus on the individual learner to construct their own understanding of the world by themselves with limited guidance from the teachers. Constructivist pedagogies are unlikely to be an effective learning approach until schemas are well developed (Hobbiss, 2018). Hobbiss proceeds with giving an example of a learner discovering through trial and error a concept and limited teacher guidance, something that is time-consuming and eventually produces only a single partial representation which is context-dependent. As explained through neuroconstructivism, that information is easily accessed subsequently only after learners are exposed to several, overlapping partial representations which can be enhanced through repetition, approximately three to four times

(Hobbiss,2018). Therefore it is not the discovery of a concept that is important for successful learning but the recurrent exposure to it and practice in accessing that information multiple times and in multiple ways (Hobbiss,2018). This can be achieved, for instance, through explicit instruction and peer discussion and collaboration.

Sometimes learners understand topics the way their instructor wanted them to understand them, sometimes they fail in learning anything, but often learners understand information different from how it was intended; partially and distorted (Gilbert et al.,1982). Based on constructivism, this is due to the fact that our surroundings are understood through personal interpretation (Taber,2011) based on current knowledge thus learners in a classroom construct a personal perception of what they are being taught. The constructivism idea supporting that knowledge is constructed individually as a response to the specific experience and previous ideas fits the notion of partial representations explained through neuroconstructivism (Hobbiss,2018).

Often, memories of a topic taught, are merely records of events but reconstructions of an experience based on an impression of experiences grouped in a similar manner (Taber, 2011). Information is translated into neuroelectric signals that enter the brain through the senses that represent the surrounding world through perception and cognition (Taber,2011). Since students are no tabula rasa, Taber (2011) argues that a constructivist teaching approach is not in line with building knowledge from nothing but rather building knowledge upon and with already available cognitive resources. Effective constructivist teaching, albeit student-focused concerning the way knowledge is built by the learner, is hands-on as teacher actively guides so as to assist in knowledge construction.

Meaningful Learning

> “ If understanding is the aim of much teaching, ability to reproduce given statements and definitions is of limited interest. So although learning by rote is an important phenomenon, much of formal education (and informal learning, for that matter) is about a different kind of learning: what Ausubel termed ‘ meaningful’ learning. “ (Taber,2011 p 43).

What Ausubel describes as meaningful learning takes place when new information is linked to students' existing knowledge. The brain allows learners to interpret their surroundings in meaningful ways by reflecting on existing cognitive resources from which they make sense of their world. Information developed is encoded within the context of the experience which reflects the state of the surroundings at the time when the information was constructed (Hobbiss, 2018). As Ausubel stated, in order for meaningful learning to be attained it is necessary for learners to have "1) some relevant prior knowledge that relates to the new information that needs to be learned, 2) material to be learned must be meaningful on their own, and 3) a student must consciously choose to incorporate this meaningful material into their existing knowledge" (Bretz, 2001 p.3). Considering that the learner has the responsibility to engage and link prior knowledge with new, that new knowledge must be constructed by the learner through experiences (Galloway et al., 2015). Meaningful learning directly contrasts rote learning in which new information is not connected substantively to existing one, but just memorised (Bretz, 2001).

Novak's (2010) theory of education known as human constructivism classifies those experiences in three categories, cognitive, affective and psychomotor. Successful integration of thinking, feeling and doing leads to meaningful learning (Galloway et al.,2015). Even though from students' perspectives, the psychomotor or doing domain is the core aim for an undergraduate laboratory while the cognitive and affective are less noticeable (Galloway et al, 2015), the theory of human constructivism states that meaningful learning will be attained only when the educational environment provides learners with experiences that require them to connect knowledge across those three domains. Consequently, "meaningfulness could promote longer lasting or maintained situational interest " (Renningerr et al., 2018 p.2) , something that, as aforementioned, impacts learning positively. However, when considering Ausubel's theory of assimilation, only one of the three factors mentioned are controlled by the teacher. Students bring prior knowledge albeit, usually, misconceived and they have full control on whether they will choose to forgo rote learning in favour of meaningful learning (Bretz, 2001). This leaves the teacher with the option to just organise material learned in ways that are relevant to the students' existing knowledge and be sufficiently interesting so that they will choose to make that link (Bretz, 2001). At this point, Novak's Human constructivism becomes useful as it provides guidance on how teachers can help students to achieve meaningful learning (Bretz, 2001) which "enables real learning, generates greater retention and facilitates transference to other real life situations" (Vallori, 201 p 199). Novak believes that education must enable people to construct their knowledge with experiences integrating the cognitive, affective and psychomotor domain that will empower students for commitment and responsibility (Bretz, 2001).

Galloway and Bretz's research (2015a;2015b;2015c) on learning in the in the chemistry laboratory at university explored undergraduates' perspectives of learning through Novak's theory of meaningful learning. Considering that the cognitive, affective and psychomotor domains must be integrated in order for meaningful learning to take place, undergraduates must actively attempt to do so while doing practical work. Through a learning in the laboratory instrument, the researchers (2015a) measured undergraduates' expectations before and after laboratory courses. General chemistry undergraduates were expected to demonstrate greater change between pre- and post-tests due to the limited laboratory experience prior to starting university (2015a). Organic chemistry undergraduates who have already studied for a year in the laboratory, were expected that their ideas about learning in the laboratory would change less than general chemistry students (2015a). Results indicated that practical work curricula are developed focusing on the cognitive and psychomotor domains (thinking and doing) but do not consider undergraduates' feelings (2015a). General chemistry and organic chemistry undergraduates change similarly from pre- to post- tests for all three domains as organic chemistry scored lower consistently on the test than general chemistry undergraduates (2015a) indicating less positive beliefs towards meaningful learning. Students in both courses claimed that their experiences failed to meet their expectations (2015a). A cross-sectional study by Galloway and Bretz (2015b) showed trends where cognitive expectations went unfulfilled in both general and organic chemistry and affective expectations were diverse among undergraduates. A longitudinal study (Galloway & Bretz, 2015c) was carried out to explore how undergraduates' perceptions about learning in the laboratory changed over two years of chemistry laboratory instruction. Findings supported previous conclusions and it was found that undergraduates reset their expectations for organic chemistry, meaning that despite their unfulfilled expectations in the previous year studying general chemistry, they still held high expectations for learning. Undergraduates showed similar patterns across two years as for the cognitive and affective domains as they started with high expectations that went unmet. However, their affective experiences remained constant over time with equal numbers of undergraduates increasing and decreasing their affective experiences either by adjusting their behaviour or lowering expectations to align with negative experiences. Comparing with cross-sectional studies (Galloway & Bretz, 2015b) undergraduates reported high expectations for general chemistry that went unmet and set the same high expectations for organic chemistry that went unmet again. Additionally, undergraduates in the longitudinal study demonstrated a decrease in the second semester for both cognitive and cognitive/affective domains. For the cognitive domain, there was a larger change from the pre-laboratory (pre-semester) to post-laboratory (post-semester) for both general chemistry and organic chemistry than when comparing the post-laboratory for semester 1 and post-laboratory for semester 2.

Engagement theory

Engagement theory is very similar to the meaningful learning theory and promotes effective learning by focusing on both affective and cognitive domains. Kearsley and Schneiderman (1999) first introduced engagement theory, which outlines how students must be actively involved in project-based learning activities through connection with others and meaningful activities, ideally with the use of technology. The theory explains how students can get motivated and become involved in an activity, in this case practical work, and how this engagement becomes enhanced when students have a sense of belonging, competence, and that the activity is relevant and important to them (Kearsley & Shneiderman,1999).

Its core principles include the 'Relate' factor, which emphasises the importance of communication and teamwork, the 'Create' factor, which suggests that an activity should be creative and purposeful, and the 'Donate' factor, which motivates students to apply their learning experiences in the real world (Milliszewska & Horwood,2004)

Engagement theory suggests that in the context of practical work, students are more inclined to engage in practical work when they feel like they are included in the science community, when they are confident in their abilities to perform in practical work activities, and when they understand the relevance of practical work in their everyday lives but also to the science community (Kahu,2013).

Collaboration opportunities, clear instructions,direction, and connections to the real-world are all examples of practical work built with engagement theory in mind. According to both the Meaningful Learning and Engagement theories, creating a favourable learning environment promotes motivation which as a result promotes learning.

The present research

While the Covid-19 pandemic restrictions temporarily forced most of the undergraduates switch to distance learning and prevented access to laboratories, the science education community has been given the opportunity, a real-life scenario, to examine the teaching of sciences without hands-on work (Kelley,2020) The laboratory, once considered as the 'essence of scientific learning' (Abrahams,2011), as well as the purpose it serves in education, is now shown to be reconsidered. As a result, even more now than before considering the new status quo in an almost post-pandemic world, examining the effectiveness of practical work and its affective value on undergraduates, especially in tertiary life sciences where there has been limited research, is a productive line of research.

Chapter 3 Methodology

Introduction

This research study aims to explore the effectiveness of practical work in higher education, in terms of the conceptual development of the subject, along with its affective value for undergraduates undertaking it.

A case study, consisting of interviews, questionnaires and observations, has been identified as the methodology to be used to obtain an in-depth detailed understanding of how practical work is being undertaken at the current university of choice. The data collected will be analysed and interpreted from different perspectives in order to answer the research questions. A combination of qualitative and quantitative methodologies will be employed, to enable data to be analysed across and within different years. Results can be compared to identify similarities and differences in trends, so as to increase reliability and allow a wider exploration of what takes place in a university laboratory (Gustafsson, 2017). An empirical study with a small sample size can still yield rich data if it directly addresses and elucidates the theory proposed by the theoretical framework or model.

Information power is linked to the level of theoretical background available that is relevant to the study. The theoretical background of this research is based on the model of Abrahams and Millar (2008), which was applied to secondary school science students to assess effectiveness of practical work. Existing knowledge has now been applied to the case of undergraduates studying science in higher education. The already published theory, albeit related to a different educational level, has a common denominator of relating to practical work in sciences, and has therefore established some foundations. The use of Abraham and Millar's (2008) model in secondary education explores, through its two levels, the importance of the hands-on more technical domain in doing and generating data as intended, as well as the incorporation of cognitive processes while doing, using ideas that were intended to be used for the experiment. Even though the intended scientific ideas are not required to guide undergraduates' actions as in Abrahams and Millar's (2008) study because a detailed laboratory protocol is provided in their lessons, acknowledging and understanding how scientific ideas underpin those scientific based actions and how they can be used as a prism to reflect on data collected is vital. In addition to the aforementioned, Tiberghien's (2000) model enhances that of Abrahams and Millars' (2008) and highlights the importance for linking the domain of observables with the idea of domains and is equally applicable to practical tasks in which scientific knowledge or an aspect of scientific enquiry procedure is required. For the same model, even though the second level (Level 2), in secondary education, is concerned with recalling actions in the domain of observables and demonstrating an understanding of ideas after the experiment in the homonymous domain, this can be equally applied in tertiary science education as procedures and scientific actions are meant to be developed and practised in an automatised way in the long-run therefore recalling is necessary. Additionally, undergraduates should, similarly to secondary education, demonstrate that they can understand the ideas the task was designed to help them learn as those ideas will be used in the interpretation of the results acquired. As Abrahams (2005) states, the theoretical framework imposes a way of seeing practical work that can ensure internal validity as well as replicability as it differentiates the activities between the domains of ideas, knowledge, and the domains of doing.

Moreover, Novak's theory of meaningful learning (2010) is used in order to understand whether practical work contributes to meaningful learning, and specifically in the affective part of the tripartite model 'think-feel-do'. Similar to Novak's (2010) theory of meaningful learning, engagement theory (Kearsley & Shneiderman, 1998) assumes that students enhance their learning by enmeshing intellectually, socially and behaviourally in their learning environment , something that shares fundamental underlying ideas of students being meaningfully engaged in learning activities through interaction with worthwhile tasks. Based on this conceptual framework, engagement metrics are based on involvement, interaction and participation. Whilst it has been observed that some studies, with similar goals to this current study, are concerned with engagement theory (Zumbrunn et al., 2014) using engagement as a predictor for achievement, here achievement or effectiveness is defined as conceptual understanding and development of skills. In this study, the focus is not placed on the engagement aspect but effectiveness is separated and observed through the lens of the three domains, cognitive affective and psychomotor, that meaningful learning constitutes of.

This chapter starts with a brief background on the methodological approaches used in related literature, and an introduction to the paradigm by which this study is guided. The pilot study is then discussed, along with necessary changes made that shaped this research, as well as ethical considerations.

Background

In recent years, most studies concerned with the effectiveness of practical work have carried out investigations using a similar approach, yielding results that favour the value of practical work as a didactic tool for teaching sciences (House of Commons Science and Technology Committee, 2002). Some seminal studies (Beatty & Woolnough, 1982; Kerr, 1963) provide insights into teachers' and students' views of practical work; these mainly repeat a rhetoric, while presenting results with patterns similarly found in other studies (Abrahams & Millar, 2008). Crossley and Vulliamy (1984) reported that a traditional approach, such as the distribution of questionnaires, is unlikely to be an actual representation of the reality in a laboratory, as participants often avoid reporting the disadvantages of a teaching practice. Interviews alone are prone to the same limitations, as respondents fail to provide real insights (Abrahams & Millar, 2008; Cohen et al., 2000).

The aim of this research study is to explore the impact practical work has on undergraduates, in terms of the development of their conceptual understanding and skills, as well as their affective effect. Exploring undergraduates' opinions on practical work while being present in the laboratory during a practical lesson can elucidate what is taking place, avoiding the limitations of possible rhetoric coming from retrieving data from questionnaires only (Millar & Abrahams, 2009). The study intends to investigate the effectiveness of practical work tasks in aiding undergraduates' conceptual development of scientific knowledge, based on what the lecturer intended them to learn, and whether such work keeps undergraduates motivated and interested. During observations, undergraduates were asked subject-related questions, in order to determine whether they understood the theory behind the practical task they are undertaking, and to test their ability to use equipment and do the necessary tasks required to successfully finish the practical.

This research study aims to explore the effectiveness of practical work from different angles, exploring lecturers' and undergraduates' views on practical work, as well as presenting the reality of how it is manifested in a university laboratory during practical activities. By exploring the relationship between reality and possible rhetoric, through examining undergraduates' and teachers' views while comparing them to laboratory observations, this research will attempt to assess realistically and without bias the value of practical work, based on empirical evidence – rather than through opinions that, unconsciously, are influenced by personal interest in the subject.

With regard to methodologies, according to Beatty and Woolnough's report (1982), a questionnaire can provide a clearer idea of the participants' view – in this case, lecturers' and undergraduates' ideas – of practical work. However, what the participants claim might not reflect what they actually practise in the laboratory. Getting closer to the laboratory environment and interacting with lecturers and undergraduates during a practical work lesson, along with the aforementioned interview and questionnaire techniques, can help triangulate data and provide a detailed portrayal of practical work in a university, while enhancing reliability and validity (Crossley & Vulliamy, 1982). Choosing to conduct a case study and collect data from the School of Life Sciences at the selected university will maximise ecological validity, with a detailed and multifacet analysis. Consequently, as suggested by Thomas (2017), if a case study focuses on a particular example of interest, approaching it from different angles, it can identify the why's and how's of the research questions, and therefore obtain a richer, multidimensional and balanced view of the reality. Furthermore, with regard to ecological validity, Crossley and Vulliamy (1984) suggested that this can affect the generalisability of a study, in terms of whether conditions in one setting can be expected to be found elsewhere. This issue is addressed by collecting data from different programmes within the School of Life Sciences at the chosen university.

Paradigm / Philosophical Approach

The paradigm that this thesis is situated within is Pragmatism. According to philosophers (Alise & Teddlie, 2010; Biesta, 2010), this is a pluralistic approach that allows the elucidation of participants' behaviours, beliefs, and eventually the consequences following those behaviours, through a combination of research methods. A mixed-methods approach "[is] a pragmatic way to understand human behaviour" (Kivunja & Kuyini, 2017, p. 35). It advocates a relational epistemology whereby the researcher develops insights through the way participants interact with each other and with their environment. Thus, it is a non-singular reality ontology, explaining that each individual has their own unique reality; it is a mixed methodology approach, and a an axiology driven by values (Kivunja & Kuyini, 2017).

With regard to methodological considerations, the pragmatist approach allows the combination of different qualitative and quantitative methodologies, so as to best represent the study and provide answers to the research questions.

Ontology, as discussed by Healy and Perry (2000), is the reality as investigated by the research; through the pragmatist lens, this is regarded as knowledge which is uncertain and changing (Onwuegbuzie et al., 2009). This aligns with practical work as a concept, as due to alterations in curriculum design, teaching methodology and student participation, its nature is dynamic. Accordingly, Vygotsky (1978) explained the ontological considerations in the pragmatist paradigm as recognising that the educational process is constructed by humans and is not considered as static knowledge (Zainuddin, 2019; Vygotsky, 1978). In pragmatism, perspectives from multiple sources are required; therefore, the effectiveness of practical work can be observed through in-laboratory observations of undergraduates and members of staff.

As Dewey (1909) explains with regard to epistemological considerations, reality can be formed through experiencing the environment. To understand reality, it is important to observe practical work in the laboratory, and to socially interact with undergraduates and members of staff, so as to understand how truth is created in certain circumstances.

Lastly, the axiological element helps to determine the research design in terms of balancing the researcher's and participants' values, in order to address ethical considerations when conducting the research. The research approaches used in collecting data ensured that every participant was treated with fairness, the laboratory environment was taken into consideration, and the learning process was interrupted to the minimum, so as to gather necessary information that would be deemed as valuable when reviewing the findings.

Pilot Study

Rationale

Before beginning the main data collection phase, and after an extensive review of the published literature, it was decided that a small-scale pilot study should be undertaken in order to prepare and ensure that logistics and possible issues were considered at this early stage. Initially, the pilot study was concerned with procedural issues regarding practicalities that might arise during data collection, since observations would be made in a natural real-life laboratory setting, with multiple external factors that might affect the flow of the research.

Firstly, an evaluation of the digital recorder was required, to ensure that observation recordings would be clear enough and of sufficient quality to be transcribed after data collection. In addition, although audio-recording observations was deemed to be the best option for the laboratory setting, since the usual duration of a lesson is 2–4 hours, participants' behaviour had to be observed, to ascertain that recording the discussions would not make them uncomfortable. King et al. (2018) reported that participants who agree to be audio recorded while interviewed feel uncomfortable at the beginning, but they start to become accustomed to it when the discussion is engaging and interesting. Furthermore, the observation tool had to be tested regarding its validity in measuring conceptual understanding, and quantifying correct and false responses.

In addition, obtaining informed consent from participants was a critical part of this study, as a decision had to be made regarding how the aims of the research would be communicated and how participants would be contacted (electronically or in person). This is because laboratory classes consist of a large number of students, and it would be difficult to distinguish consenting individuals from those who had declined to participate in the study during the lesson. Moreover, difficulties could arise due to the fact that seating arrangements are usually random. Time also had to be considered during observations, since students were required to be fully engaged with the practical task in order to finish on time. As a result, a consistent, uniform approach had to be taken, in order to ensure that all participants would have the opportunity to engage in similar discussions built on the same foundations; and most importantly, that they would not be disturbed or interrupted during their lesson. Time available for interacting with students would play an important role in deciding whether separate undergraduate group interviews, or talking to participants during the lesson, would have the potential to generate adequate data for answering the main research questions. Lastly, student and lecturer questionnaires had to be discussed with participants respectively, to ensure clarity and appropriacy of questions. Overall, a pilot study would help to ensure that the research questions which initially emerged from the literature review were appropriate for developing a strategy that would address the main issues, and yield high-quality data that would achieve the main objectives of the study.

Pilot study

The pilot study took place at a university in the East Midlands of England, at the department of life sciences. The pilot study involved two practical lesson observations in the first week of March , one for Year 1 and one for Year 2, attended by undergraduates of five different degrees, for whom the module was either core or optional. The practical lessons observed were selected based on the modules available in the particular week the pilot study was scheduled to take place, with a precondition that they would not include any on-the-spot assessments that could potentially affect the way a usual practical lesson is performed, and might give a non-representative image of the practical lessons in the main data collection.

Emergent Issues

The pilot study was important in that the findings helped to refine the research questions, to validate the observation instrument and its usefulness, and to shape the research strategy that would be adopted for the main data collection. Initially, it was realised that laboratories were booked for longer, and practical lessons were timetabled to last for more hours than were needed to complete them, in order to allow time for potential errors and setbacks, as well as giving students more time to finish their tasks, if required.

Regarding the evaluation of the digital recorder and the audio quality, within the laboratory setting it was evident that the device had to be close to the participants while talking to them. Initially, an external lavalier (‘tie’ clip-on) microphone was used, to make recording more discreet. However, when listening to the recordings at the end of the practical lesson, they were found to be inaudible, since the microphone was not close to the participants. Moreover, considerable background noise was captured, as the clip-on microphone did not have a filter to eliminate sounds caused by friction with clothes or movement. For this reason, the researcher decided to use the recorder on its own without any accessories, and it should be placed closer to the participants when interviewed. Indeed, this decision proved to yield better, and audible, data.

In terms of participants’ behaviour while recording, the recorder, which is palm-sized, was initially held in the researcher’s palm to make it less visible to the participants, even though they were aware that conversations were being recorded. It was apparent from the first discussions that undergraduates were bothered by this, since they felt that the recorder was concealed, as shown in their attempts to catch sight of the device. In addition, although it would have been better to place the digital recorder on the bench, this did not comply with health and safety standards, as for most of the time, table tops had to be treated as contaminated.

For this reason, and from that moment onwards, the recorder was hand-held in plain sight, so as to limit ‘reactivity effects’. According to Cohen et al. (2000), the term ‘reactivity effect’ describes a change in participants’ behaviour when they are placed in novel situations or when they feel that they are under scrutiny; an effect that an interview situation might trigger. However, one of the limitations of using a digital recorder was that audio could not capture the surroundings, or what was happening in the laboratory in terms of lesson structure, participants' non-verbal expressions or behaviour. Thus, it was decided that note-taking had to be incorporated into the methodology, in order to describe, from the observers' eyes, what was happening at that time in the laboratory.

Whilst the initial plan was that the researcher would observe passively, it was clear that this made undergraduates feel that they were being observed and examined. Therefore, a more active role had to be taken: the researcher was given five minutes to explain to undergraduates the purpose of the visit; the research confidentiality, informality and anonymity; and that the research was part of a PhD study, meaning that the researcher was a student. An interviewer's age, according to Shafer and Navarro (2016) and Smith et al. (2017), can affect the interview, since young interviewees respond in a different way in the presence of someone who is close to their age. As the PhD researcher was a student, this made undergraduates feel comfortable, in a sense that they could communicate with someone who was close to their age. Encouraging discussion and intentionally asking questions in a non-judgmental way, along with the aforementioned factors, made undergraduates keen to openly discuss their thoughts; and they had no hesitations about making mistakes when being asked a subject-specific question, since the researcher acted with "deliberate naiveté" (Manzano, 2016, p. 11).

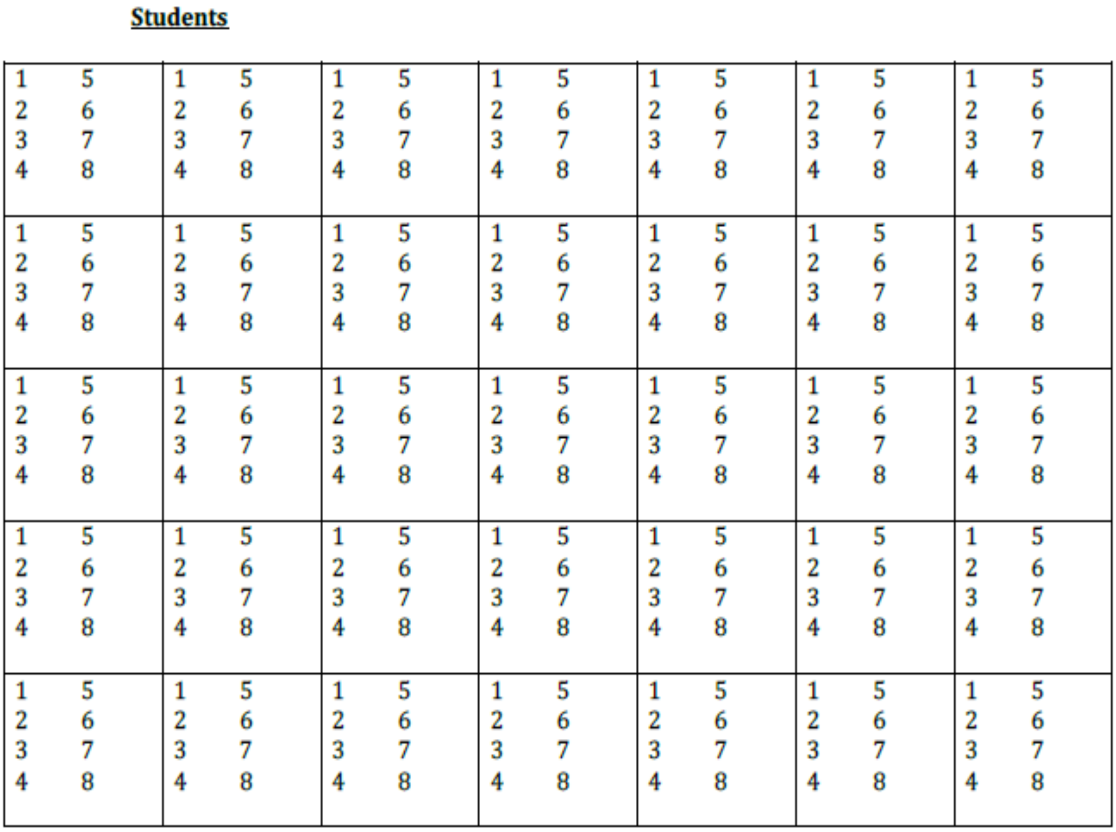
The observation tool was filled out at the beginning of the lesson, to clarify the practical lesson's objectives with the lecturer. This was useful in order to know what to look for while interviewing and observing participants. For instance, some lecturers were interested in the participants' acquisition of skills, whilst others focused on building knowledge and trying to visually support theory by giving undergraduates hands-on work. Initially, the observation instrument was designed with a table (Figure 2) that represented a potential seating plan of a laboratory class, with numbers representing the questions asked; this was intended to quantify the effectiveness of practical work at level 1 and level 2. For level 1, in response to the question "Do students do what they were intended to do and see what they were intended to see?", the letters F (Fully), S (Sufficient), I (Insufficient) and N (None) would be used as options next to the relevant questions (Figure 3), thus providing an opportunity to draw a conclusion and calculate an average for students' actions. Although, theoretically, this was an accurate way of recording undergraduates' responses and behaviour, it was evident that observations in a real-life laboratory setting could not be structured. As a result, this part of the observation tool was ineffective, because firstly the laboratory was large, as was the number of undergraduates.

Secondly, undergraduates were interviewed randomly and at different times, since might be busy or trying to catch up with the experiment, and therefore could not be interrupted. Equally important was the fact that key questions had to be incorporated in a discussion, to make the interview sound more natural and friendly, and therefore make participants feel more comfortable rather than that they were being assessed. Asking undergraduates a series of questions made them feel uncomfortable and unwilling to speak freely.

Moreover, questions were not always relevant to the undergraduates' stage in the experiment during the interview. For the first part of the question on the sufficiency of undergraduates' actions during the experiment, the researcher decided to assess it qualitatively based on an overall view: this was because the aforementioned standardised procedure was difficult to use, as undergraduates were at different stages of the experiment at different times and could not be assessed, in all aspects, at once.

Completing each question in each box (representing a student) at different times by returning back when appropriate was impossible, given that the large number of undergraduates in the laboratory would require their identification, since it was difficult to remember students, and which box corresponded to which face. For these reasons and after the initial pilot study, it was decided that the observation instrument in Figure 2 could not be utilised for the main research phase and data collection.

Figure 2
Students' laboratory seating plan with numbers representing the questions asked

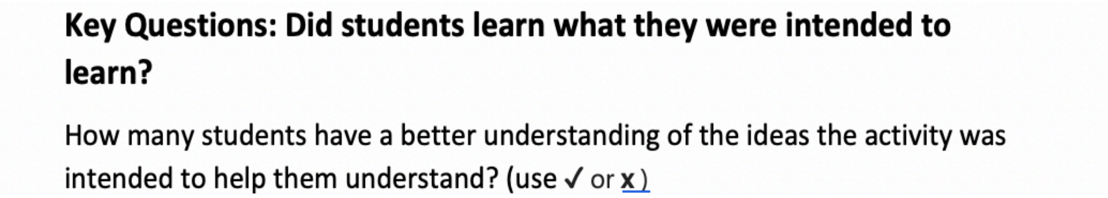


Students

1 5 2 6 3 7 4 8	1 5 2 6 3 7 4 8	1 5 2 6 3 7 4 8	1 5 2 6 3 7 4 8	1 5 2 6 3 7 4 8	1 5 2 6 3 7 4 8	1 5 2 6 3 7 4 8
1 5 2 6 3 7 4 8	1 5 2 6 3 7 4 8	1 5 2 6 3 7 4 8	1 5 2 6 3 7 4 8	1 5 2 6 3 7 4 8	1 5 2 6 3 7 4 8	1 5 2 6 3 7 4 8
1 5 2 6 3 7 4 8	1 5 2 6 3 7 4 8	1 5 2 6 3 7 4 8	1 5 2 6 3 7 4 8	1 5 2 6 3 7 4 8	1 5 2 6 3 7 4 8	1 5 2 6 3 7 4 8
1 5 2 6 3 7 4 8	1 5 2 6 3 7 4 8	1 5 2 6 3 7 4 8	1 5 2 6 3 7 4 8	1 5 2 6 3 7 4 8	1 5 2 6 3 7 4 8	1 5 2 6 3 7 4 8
1 5 2 6 3 7 4 8	1 5 2 6 3 7 4 8	1 5 2 6 3 7 4 8	1 5 2 6 3 7 4 8	1 5 2 6 3 7 4 8	1 5 2 6 3 7 4 8	1 5 2 6 3 7 4 8

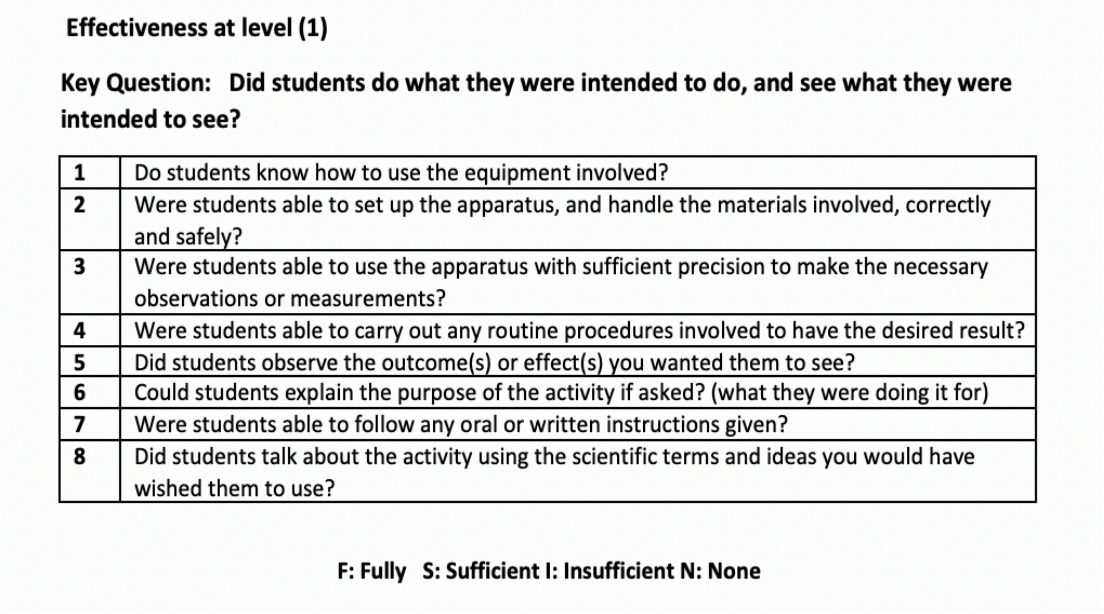
Figure 3

Observation instrument questions to be answered using relevant word coding on students' seating plan



Key Questions: Did students learn what they were intended to learn?

How many students have a better understanding of the ideas the activity was intended to help them understand? (use ✓ or x)



Effectiveness at level (1)

Key Question: Did students do what they were intended to do, and see what they were intended to see?

1	Do students know how to use the equipment involved?
2	Were students able to set up the apparatus, and handle the materials involved, correctly and safely?
3	Were students able to use the apparatus with sufficient precision to make the necessary observations or measurements?
4	Were students able to carry out any routine procedures involved to have the desired result?
5	Did students observe the outcome(s) or effect(s) you wanted them to see?
6	Could students explain the purpose of the activity if asked? (what they were doing it for)
7	Were students able to follow any oral or written instructions given?
8	Did students talk about the activity using the scientific terms and ideas you would have wished them to use?

F: Fully S: Sufficient I: Insufficient N: None

An important decision of ethical concern had to be taken during the pilot study, with regard to participants' consent. Initially, consent forms were planned to be sent electronically via email. However, this would require access to undergraduates' personal information and data from the School of Life Sciences, without undergraduates' consent. In addition, taking practicality matters into consideration, it would had been difficult to identify undergraduates who gave consent and agreed to participate in the research, since asking them to identify themselves during the practical lesson would breach their anonymity.

For this reason, upon entering the laboratory, the researcher was given some time to introduce herself, explain the research, highlight some key points concerning ethics and participation, and give undergraduates time to read the information sheet and decide whether they were interested in participating in the study. It was made clear that undergraduates should sign the form before the beginning of the practical and leave it next to them in order for the researcher to identify interested participants, without disturbing them, so as to approach them and chat while walking around. Moreover, even if the forms were signed, undergraduates were always asked prior to chatting whether they wanted to have a discussion, since they were allowed to opt out at any point. They were also asked whether this was a good time to talk to them, to ensure they were not being disturbed during their experiment. Forms were collected at the end of the practical.

The researcher approached lecturers during the practical lesson, to ask if they would be interested in participating in the study and being interviewed. Furthermore, the procedure and what the interview would involve were discussed. After the practical lesson, interested lecturers were contacted via email in order to schedule a meeting, An information sheet was provided on the day of the interview, along with a consent form, so that the lecturer could decide whether they wanted to proceed.

Regarding timing, another important finding that emerged from the pilot study was that undergraduates were not ready to interact with the researcher at the beginning of the practical lesson, since they were still considering the protocol of the experiment, planning and clarifying their steps with lecturers present in the laboratory. While it was difficult to have general discussions that were not directly related to the experiment while walking around, most experiments had waiting times when undergraduates were waiting for a machine cycle to finish; this was the best time to talk to them and discuss about their general perceptions of practical work. In addition, the researcher had the opportunity for discussions with undergraduates at the end of the experiment, to recap and talk about their thoughts on the lesson.

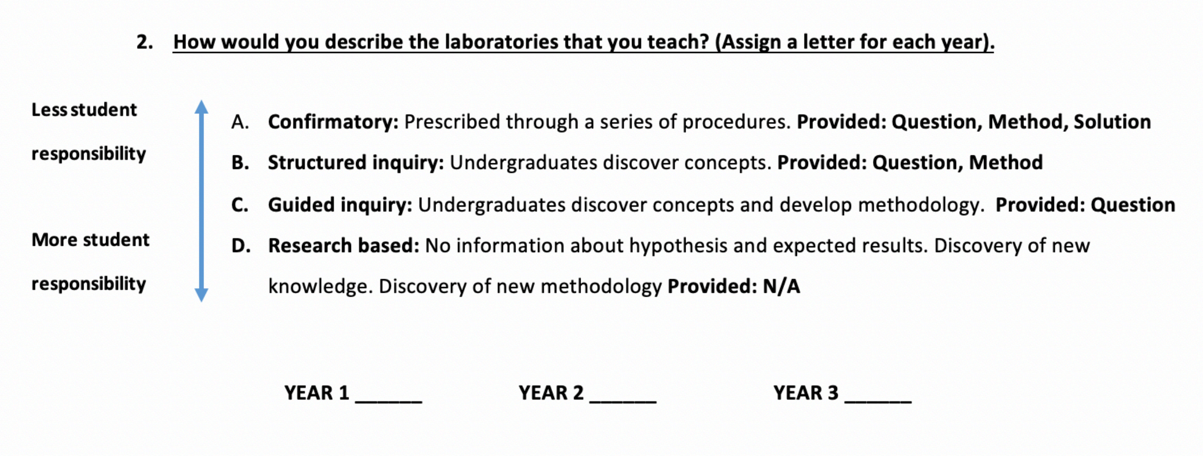
It also became apparent that practical lessons were long enough to allow time to talk to almost all of the undergraduates and obtain adequate responses and data. For this reason, the initial idea of recruiting undergraduates for separate group interviews was considered unnecessary, since the researcher could collect a variety of responses in class, rather than talking to an isolated selection of undergraduates who would be willing to participate in an interview after class.

The questionnaire, which was developed and already validated by the Bretz Research Group (Galloway & Bretz, 2015) was discussed with a group of four life science undergraduates who were willing to assess the questions and give feedback on their clarity and relevance to their course.

Since the laboratory observations required considerable time, interviews with the lecturers were scheduled at the lecturers' convenience, at their earliest opportunity. For feedback on the practical lesson and its effectiveness, the researcher had a brief discussion with the lecturers after the practical lesson, when their views and recollections were clear. Lecturers were willing to contribute to the research and spend time engaging in discussion about the lesson. With respect to the lecturers' questionnaire, the two lecturers involved in the pilot study provided guidance and gave feedback on the activities. In particular, lecturers reported that the choices (Figure 4: A, B, C, D) for the second question of the questionnaire, asking how would they describe the laboratories where they taught, were not particularly relevant to the practical activities taking place in the department. For this reason, lecturers were asked directly during their interview about the types of practical activities that they ran, in terms of student responsibility (less / more) for each year; this showed the openness of the activities, and what skills they wanted students to acquire from their practical lessons.

Figure 4

Lecturers' questionnaire. Activity 2 required slight instruction modifications



2. **How would you describe the laboratories that you teach? (Assign a letter for each year).**

Less student responsibility

More student responsibility

A. **Confirmatory:** Prescribed through a series of procedures. **Provided: Question, Method, Solution**
B. **Structured inquiry:** Undergraduates discover concepts. **Provided: Question, Method**
C. **Guided inquiry:** Undergraduates discover concepts and develop methodology. **Provided: Question**
D. **Research based:** No information about hypothesis and expected results. Discovery of new knowledge. Discovery of new methodology **Provided: N/A**

YEAR 1 ______ **YEAR 2** ______ **YEAR 3** ______

Furthermore, concerning the semi-structured interviews with the lecturers, some points that were raised during discussion yielded richer data that answered the research questions in more detail. For this reason, more questions were added to the list, which could be used to initiate discussion in the main data collection.

Finally, the pilot study was valuable for providing insightful data that were used to refine the initial research questions. During the pilot study, it was evident that there were different types of practical work lessons being undertaken at the department of life sciences. Such lessons also had different aims and objectives, since some lecturers prioritised the acquisition of skills, whilst others wanted undergraduates to gain more theoretical knowledge on the subject through hands-on experience. For this reason, an additional research question emerged regarding the aims of practical work (in general and for each year) at university level, based on lecturers' perceptions. As Ogborn (1978) argued, practical work does not have a single purpose, but its purpose depends on the person designing the lesson and the students the lesson is addressed to. Indeed, it was observed that lecturers believed that the aims of practical work lessons were different for each year.

In terms of the appropriateness of a case study strategy, it was evident from data collected that observations and interviews, along with the distribution of questionnaires, would elucidate areas of interest and would provide more spherical answers to the research questions.

Ethics

This research study received ethical approval from the Chair of the School of Education Research Ethics Committee. The selection of the university was based on convenient accessibility, proximity, and the researcher's pre-established relationships with the institution.

The research was conducted with undergraduates in years 1 and 2, in order to limit distractions and avoid any obstructions to undergraduates in year 3, who were understandably involved and focused in undertaking their individual research projects. In addition, observations were made in practical lessons that did not include any on-the-spot assessment, so as to avoid distracting undergraduates from their academic duties. Data collection from observations was essential in order to understand and gain insights into the real activities in the laboratory setting when practical work is being undertaken by undergraduates. The lecturers were invited to complete a questionnaire and participate in a short interview at their convenience, expressing what effect they thought the practical had on students, whether the outcomes had been met, and clarifying some of their questionnaire responses.

The university of interest was recruited according to access availability, participants' consent, and schedule. The Head of School and the Head of College of Science were contacted and received a research proposal along with the approved ethics form, to give them time to clarify questions they had regarding the project's structure, scope, aims and goals, following an in-person meeting.

Upon approval, no participants were included in the research against their will, and they also were able to withdraw at any point up to the anonymisation of the data. They were all made aware that participation was voluntary, and no influence was exerted to persuade undergraduates or lecturers to take part in this research. Refusal attracted no discouragement and withdrawal did not require permission. No payment or reward was offered.

Undergraduates were given an information sheet and consent form at the beginning of the lesson, while also being informed about confidentiality and protection policies, so they could decide whether to opt-in for the audio-recorded interviews. Consent forms were placed next to the undergraduates so that the researcher could see who wanted to participate, so as to limit disturbance. Initially, consent forms were planned to be sent electronically via email, but the researcher decided that since this would require access to the university's data, undergraduates should be informed on the day of the observation. Moreover, regarding practicalities, sending electronic consent forms would require the identification of undergraduates during observations, which would breach anonymity.

The research spent time explaining what was being asked from participants, in simple language that an ordinary person could understand, and information was appropriate for the social and cultural context in which it was given, in order to help undergraduates make an informed decision on whether they wished to participate. Interviews and questionnaires did not involve any topics or issues that might had been sensitive, embarrassing or upsetting to the individuals. Undergraduates were also informed that this research would be part of a PhD student project.

Anonymity of the participants was maintained, and no names were requested on the questionnaires or during interviews. During the write-up of the thesis, no details were disclosed to the university which participated in the study, and word codes were used instead of names in order to quote responses from interviews. Questionnaires were numbered for inventory purposes and handed out randomly, to avoid a link between data and identifiable people. Lecturers' names were not disclosed in any documents. The researcher also clarified that after returning the questionnaires, undergraduates' data could not be withdrawn, as there was no way of identifying them. Questionnaires, observations and interviews were completed during working hours at the university, under the approval and direction of the Head of School, and lecturers who agreed to take part in this research.

Hard copies were securely locked in a cabinet at the researcher's office and safeguarded in accordance with the Data Protection Act. Data were anonymised at the point of storage, and interviews were transcribed in words, breaking the link between voice and person. Data kept on a computer were password-protected and only accessed by agreed members (the supervisor and researcher). All data will be destroyed after the final award of the PhD. Paper documents will be shredded, and electronic data including audio and questionnaires will be erased, after seeking assistance from the IT services for secure disposal based on the institutional data protection standards.

Furthermore, the reseracher ensured that this research was appropriately designed prior to the investigation, and was completed to a high level of competence, so as to yield results of sufficient quality that would justify the participants' effort and time.

Research Focus

Conducting an extensive literature review revealed that although studies have been concerned with practical work in secondary education, there has been insufficient research on the impact of practical work in studying life sciences post-compulsion. The limited amount of empirical evidence on the effectiveness of practical work in developing conceptual knowledge and its affective value for undergraduates in life sciences has exposed a gap in the literature. Most studies have been repeating the rhetoric by examining participants' thoughts about practical work, rather than testing their knowledge and engaging in conversation, so as to observe the affective value practical work has on undergraduates. For this reason, it is apparent from the literature review that certain questions are yet to be satisfactorily answered:

1. Is practical work effective as a learning strategy to assist conceptual development?
2. To what extent does practical work have an affective value for university undergraduates studying science?
3. What are the aims of practical work in higher education?

Therefore, an appropriate research strategy had to be developed in order to answer the aforementioned questions.

Research Strategy

Case study characteristics

From its early stages, the pilot study revealed that each practical lesson could be treated as a separate entity in the case study (the university) , as the lessons had different aims, different content, and sometimes different undergraduates. As Yin (2009) explains, case studies are designed to bring out details by using multiple data sources. This case study is regarded as multi-perspectival as the researcher considers both members of staff and undergraduates perspective as well as the interaction between them, a prominent feature in the characteristics that a case study possesses. According to the Yin approach (Moss, 2023) in a case study the research questions formulated must at least explore the defining features of a phenomenon

(What), how groups achieved a goal (Process questions) as well as questions where intensity or duration is assessed (To what extend). These criteria align with the formulated research questions discussed later (RQ1,2,3). Moreover, as Yin implies (Moss,2023) a case study will indeed answer the research questions posed as the methodology involves interviews, surveys and observations to understand what, when and to what extend practical work is effective, a contemporary and specific problem in tertiary education. Following the Yin approach further, the propositions that will be assessed were clearly defined and shaped the design of the research in terms of the people interviewed, questions asked, domains observed and data to be analysed. Therefore, the institutional setting and groups of people and events aimed to be investigated were decided so as to be tangible and readily distinguished from their context. Additionally, boundaries such as the interval explored (Semesters), actions (conceptual and skill development) as well as people (full-time undergraduate Life Science students) were set. Data collection and analysis aimed to follow a blend of qualitative and quantitative data and were followed be a pilot case. Besides data triangulation, Yin (Moss,2023) recommends the application of the chain of evidence principle where evidence from one stage of data collection and interpretation is associated with the evidence at other stages. This was decided to be achieved through the use of interviews, direct observations, participant observation and physical artifacts. Knowledge deriving from a specific setting and context are valuable and more sophisticated than that of more generalised contexts as reality is complex and the aim of a case study is to provide information on the dynamic, multifaceted and perhaps contradictory nature of participants and environments (Moss,2023).

Case study validity

Although the initial plan for this research study was to observe biology undergraduates, since they are studying one of the three core science subjects, in fact they did not accurately represent the School of Life Sciences, as biology undergraduates constituted only a small number of the total enrolled population. Moreover, practical classes involved undergraduates from different life science degrees. For this reason, it was decided to recruit undergraduates from all of the degrees offered by the School of Life Sciences.

Table 6

Three-year degrees offered at the university of choice as part of the School of Life Sciences

School of Life Sciences Degrees
BSc (Hons) Ecology and Conservation
BSc (Hons) Bioveterinary Science
BSc (Hons) Biomedical Science
BSc (Hons) Biology
BSc (Hons) Biochemistry
BSc (Hons) Animal Behaviour and Welfare
BSc (Hons) Zoology
BSc (Hons) Ecology and Conservation
Number of Students
Year 1 (n=256)   Year 2 (n=211)

With regard to external validity, this refers to the extent to which the collected data can be generalised to a broader population (Cohen et al., 2000). Because the researcher chose to focus on an in-depth case study to portray a natural social setting, the data were specific and ecologically valid, since they can be applied to other real-life settings (Andrade, 2018). However, as strengths emerge, limitations surface too, since the Achilles' heel of an in-depth case study will be low population validity: findings obtained from the accessible population may not be generalisable to the wider or total population, such as undergraduates in another institution (Abrahams, 2008; Cohen et al., 2000; Bracht & Glass, 1986).

It is common for case studies to receive criticism due to the small population size; this negatively affects any generalisability prospects (Wikfeldt, 2016; Woodside, 2010) since it is argued that the main aim of research is to generalise data to larger populations (Tsang, 2014)

Concerning the use of a case study, which in this research is defined as an in-depth real life-content empirical study (Yin, 2009), Chreim et al. (2017) states that "although some people view this [a case study approach] as a limitation impeding generalisability, it should be noted that naturalistic case studies should be judged not on the basis of generalisability but on the basis of transferability and comparability" (p. 1535). Therefore, to some extent, results can be generalisable to a wider population. As Tsang (2014) further explains, there are different ways of generalising; in the case of an empirical study, the two populations compared should share some common features, so as to justify the purpose of the generalisation. Additionally, in order to decide whether results are generalisable to a wider population it is important to first have an in-depth understanding of the study’s context; this will identify detailed information to look for, in which case studies are superior to quantitative methods (Tsang, 2014). In agreement, Bell (1987) confirmed that generalisations can be carefully made by considering the ecological validity, and whether a certain case shares similarities with another one. For instance, this case study has certain aspects which are similar to other universities where life sciences are being taught. A university with an access policy of undergraduates with an average grade B in A-level examinations might be expected to have students with similar characteristics to those in this case study, whose entry grades were the same.

Moreover, Falk and Guenthere (2006) discussed defining priorities; in this research, attention is paid to reliability, validity, triangulation, and an interpretation of findings that support or reject a hypothesis, leading to the creation of a theory. Spindler (1982) and Wikfeldt (2016) agreed that even though a case study has low generalisability, it has high ecological validity, meaning an accurate representation of an in-life situation, rather than low accuracy or “misleading information about isolated relationships in many settings” (Spindler, 1982, p. 8). Yin (2012) stated that case studies do not generalise from “samples to universes” (p. 18), but they help to explain situations in case studies similar to the case study researched. If further research shows that the outcomes share resemblances, then a hypothesis is strengthened and a theory is constructed (Yin, 2012); or should the opposite results arise, theory is undermined and disconfirmed. This process is called ‘analytic generalisation’ (Wikfeldt, 2016). Furthermore, as stated by Wikfeldt (2016) and McWhinney (1989), particularisation is preferred over generalising results, since a case study tends to study a phenomenon in depth.

In order to make this case study as ecologically valid as possible, the researcher decided to employ a mixed-methods strategy so as to triangulate different quantitative and qualitative sources of evidence (Yin, 2011). According to Venkatesh et al. (2016), Teddlie and Tashakkori (2010) and Cresswell (2014), a mixed-methods approach utilises the strengths of both quantitative and qualitative strands in order to reach conclusions that are free of limitations that would have occurred if a single methodology had been used. According to Venkatesh et al. (2016), mixed methods are defined as:

> *The type of research in which a researcher or team of researchers combine elements of qualitative and quantitative research approaches for the broad purposes of breadth and depth of understanding and corroboration. (p. 437)*

Advantages of mixed methods include the simultaneous evaluation of confirmatory and explanatory research questions, thus resulting in stronger inferences from a more robust analysis. If the methods are combined, strengths are enhanced and limitations of both methods are minimised (Cresswell, 2017; Venkatesh et al., 2013). For this reason, in this study, mixed methods were employed so as to holistically explain practical work in tertiary science education, given that existing research has been equivocal and has mainly reproduced the existing rhetoric. Two theoretical frameworks were used to guide the study, rather than solely depending on methodological approaches. The methodologies employed were chosen to serve that theoretical perspective, resulting in an in-depth understanding achieved from two different methodological approaches, in order to confirm and cross-validate findings. Irrespective of their priority or the integration of further strategies, these theoretical frameworks explicitly guided the study.

Quantitative and qualitative data were collected in phases, or as Creswell (2017) defines it, sequentially: the qualitative part was conducted first, with the intention to explore findings with participants on-site. Then the understanding was expanded through a quantitative phase, with the aim of integrating results during data analysis and interpretation (Figure 5**)**. Priority was given to qualitative data as the major form of data collection, since the emphasis was placed on what was actually happening on site; in this case, the laboratory. Furthermore, an inductive orientation was adopted, since the research is concerned with the development of themes emerging from findings. For this purpose, research questions were used to narrow down the aims of the study. With regard to the integration of data, it occurred at different stages in the research process. Although earlier approaches to the design of a mixed-methods study were primarily typological, it has been argued that mixed methods are far more complex and diverse, rather than limited to certain typological restrictions (Guest, 2012; Maxwell & Loomis, 2003; Tashakkori & Teddlie, 2003). Vankatesh et al. (2016) viewed mixed methods as being multidimensional, with different typologies incorporated so as to flexibly address the purposes of the study. After data collection, strategies for data analysis had to be incorporated in order to produce an inferred narrative (Venkatesh et al, 2013) formed from the integration of both methods; Venkatesh et al. (2013) defined this process as meta-inferences.

From an epistemological perspective, this study follows a single paradigm stance focusing on pragmatism, which according to Brierley (2017) and Creswell (2017) has been identified as a suitable option in mixed-methods studies. Creswell (2003) further explains that studies with a pragmatist approach draw assumptions from both quantitative and qualitative methodologies, in order to best address the needs of the research in finding answers to a problem.

Figure 5

Mixed-methods strategy of inquiry (Creswell et al., 2003, p. 211)

Implementation	***Priority***	***Integration***	***Theoretical Perspective***
Sequential	**Qualitative**	**At data analysis and interpretation**	**Explicit**

Research Questions

After conducting an extensive literature review, it emerged that the main research questions arising were specifically focused on the effectiveness of practical work as a teaching practice, and the affective value of practical work for undergraduates in studying their subject.

Moreover, the fact that universities do not follow a universal curriculum raised the need to discover the aims of practical work in the university of choice, in order to clarify how the term 'effectiveness' was defined by the institution. For this reason, the researcher considered effectiveness according to how the term guided the structure of the university's programme in leading undergraduates to reach certain goals. Effectiveness could mean different things to different lecturers; therefore, the aim was to observe whether there was an agreement between members of staff on what had to be achieved by undergraduates. The pilot study showed that different practical activities had different aims, and sometimes undergraduates were not expected to conceptually learn something but enhance their practical skills, and vice versa. Furthermore, regarding the affective value of practical work, undergraduates were interested in practical work for different reasons. Therefore, the researcher decided that the research questions should be narrowed down in order to follow the theoretical framework guiding this research. In particular, concerning the affective value, sub-question 1 had to be rephased to be more specific. The researcher therefore decided to continue the question by asking: "If practical work has an affective value, what is it for?"

This resulted in the following rhetorical-style research questions, some of which have a combination of quantitative and qualitative aspects that are answered using a mixed-methods approach. The research questions are independent and are not affected by each other.

1. What are the aims of practical work amongst a small representative sample of lecturers in the department of life sciences at the chosen university?
2. Are practical tasks effective in enabling undergraduates to *do* and/or *learn* what is intended?
    a. If yes, when?
3. Does practical work contribute towards meaningful learning?
    a. If so, to what extent does the affective value contribute to that meaningful learning, and what is it for?

The relationship between the questions and the research strategy was predetermined, as they guided data collection. Questions 1 and 3 were dependent on question 2, since the aims each lecturer set for the specific practical activity defined whether undergraduates were successful or unsuccessful in doing and learning what the lecturer intended them to do.

Study Sample

The study sample was decided early in this research, as it was informed by the study's main research questions. The participants of this study, undergraduates, were chosen so as to provide insights regarding how practical work affects the learning of undergraduates, and whether it has an affective value. Different year groups were included, to provide details of possible differences or similarities in the aims of practical work in higher education. In addition, lecturers leading the practical sessions were also recruited to give their perspectives on the role of practical work, and whether they felt their teaching objectives were being met by undergraduates through this practice.

According to Westbrook and Marek (1992), cross-age studies are useful because they can, for instance, provide details on the understanding of a certain concept from students across different age groups. However, although participants belonging to different age groups might not be directly comparable (Rose & Sullivan, 1993), the aim of this research study is not to directly compare undergraduates' responses based on their age or year of study, but to focus on practical work, and view variables such as different year groups through that lens. Consequently, this will aid in the understanding of possible similarities or differences in the aims of practical work for each year, and whether undergraduates' exposure to practical work, over the years, affects their feelings.

Regarding accessibility, it was important to ensure that access to the participants was permitted, as well as being practicable for this study, as argued by Punch et al. (2013). For this reason, accessibility was a major factor that influenced the total sample size and the university where the study would be conducted. Initially, the study was planned to involve multiple case studies from universities around England. However, the universities could not grant long-term access to the laboratory classes; this would be problematic for the research, as single observations would not necessarily provide in-depth information that would represent the exact practices of undergraduates and lecturers in practical work lessons. Considering the above, the researcher decided to carry out research in the UK at a university where the researcher and supervisor had professional relationships, and permission was given to access laboratories for long enough to collect data necessary for conducting this study. As a result, the university selection was based on practicality. Initially, the researcher contacted the university via email, with an introductory proposal explaining the research. The proposal outlined methodological approaches and details of what was required from members of staff and students. After permission was obtained from the Head of School of the Life Sciences department, module leaders were contacted, to discuss the possibility of attending their laboratory class and collecting data both from their undergraduates and themselves. Visit arrangements were further discussed with the head of the technical laboratory team, and the researcher participated in a health and safety introductory training.

University and Participants

The university and participants of this study, as aforementioned, were chosen based on non-probabilistic sampling, more specifically, convenience sampling. Convenience sampling is a method were participants are recruited as part of a non-random process where the population of interest meets certain practicality criteria, including easy access – in this case, access to the laboratory premises, geographical proximity and availability at a given time, and interest in participation (Etikan, 2016), which is also important (Palinkas et al., 2015; Bernard, 2002). It is assumed that participants of the target population are homogeneous, and thus would not differ from random sampling in another institution (Etikan, 2016). On this note, Kirska et al. (2013) commented that while most researchers aim to conduct studies that can be generalisable to an entire population, it is more reasonable to generalise to a subset, and then conduct additional research and generalise through it to another subset. In this way, data gathered and accumulated will test and therefore support and/or modify a model, to enhance its viability.

The institution of choice is a public research university in England, which for the last 30 years has offered undergraduate and postgraduate degrees. Being a fairly new university with fast progression, it is ranked amongst the top 30 in the UK, according to the Complete University Guide (2019). The School of Life Sciences has been running for approximately six years and has seven 3-year degrees whose access policy requires undergraduates to hold three A-level (GCE Advanced Level) qualifications with grades of BBB, equivalent to 120–131 UCAS tariff points. UCAS is a UK organisation that operates application processing for higher education. Students' examination grades are converted into numerical values that correspond to UCAS tariff points, which universities refer to for their students' entry requirements (UCAS, 2019).

Whilst the university where the study was conducted does not represent all universities in England, in terms of size, status and setting, it nevertheless shares similarities with universities of the same ranking, whose students' average entry-level qualifications match. In addition, certain programmes are accredited by a professional body in sciences; thus, universities that use such programmes must fulfil similar requirements.

Participants included first- and second-year undergraduates who were studying in the School of Life Sciences. Undergraduates had individual degree-specific laboratory classes, along with classes shared with undergraduates across the school from all seven programmes. Year 3 undergraduates were involved in their individual research projects; therefore, stakeholders advised that their participation in this research would be a form of distraction that should be avoided.

The selected university allocates approximately 3 hours a week to practical activities for the first-year students, 3–10 hours for second-years, and 3 hours for third-years, since they are mainly involved in their individual research project which is part of their dissertation.

Details on participants recruited and their role in the laboratory

The population size of Year 1 and Year 2 undergraduates in the selected department of Life Sciences were this study was conducted was 256 and 211 respectively. For Year 1, in the 9 practical work lessons observed the number of undergraduates recruited to be informally assessed on their conceptual understanding and skills was : Cell Biology (95), Biochemistry (86), Microbiology (95), Histopathology (100), and Plant Biology (52). For Year 2, again for the 9 practical work lessons observed recruited undergraduates were as follows : Immunopathology (100), Animal nutrition (40), Zoology (40), Pharmacology (48), Biology of diseases (60), Molecular Biology (136), Biochemistry (83), and Immunopathology (100) .

For the questionnaires provided before the semester 166 Year 1 and 110 Year 2 undergraduates were recruited, and at the end of the semester 140 Year 2 undergraduates were recruited with no Year 1 participants. With regard to members of staff attending the observed laboratory classes, interview and questionnaire data were acquired from a total of 14 full-time lecturers and technical staff. The roles of members of staff and their departmental position was not specified in the research as both lecturers and technical staff were part of the specific module's team in which they all equally contributed collaboratively in designing the practical work lessons. Moreover, their role and effort in the practical work lesson was the same and equal as both the lecturer and technical staff were assisting undergraduates and providing support. The only duty that differentiated members of staff from lecturers was the setting up of apparatuses and laboratory benches before and after the practical work lessons.

Sample Size

In general, as Faber and Fonseca (2014) discussed, the sample size of a research study has great significance for reliability; a large sample can avoid erroneous misinterpretations of findings due to data collected from a sample pool not representing the whole population, which will undermine external and internal validity. However, financial resources, time invested and accessibility can be obstacles to conducting a large study. Consequently, a case study was deemed the best possible approach for this research. A case study ensured an in-depth research of the target population, so as to enhance the ecological validity of the study; and mixed methods combined the strengths from both quantitative and qualitative approaches, to minimise their limitations.

In the UK, the total population of undergraduates enrolling into a life science degree in 2017/2018 was 241,830, according to data gathered by the Higher Education Statistics agency (HESA, 2019). In the university where the research was conducted, the population size for undergraduates enrolling in the life science department was approximately 250 per year. Since this case study is not aiming to represent the whole population of universities in the UK, only the number of undergraduates in the School of Life Sciences was needed, to ensure that the quantitative aspect of this study would yield representative results for the target population. Calculations were made using an online sample size calculator (Survey Monkey, 2019) and two factors (confidence intervals/margin of errors and confidence levels) were used to derive to a result that would identify the sample pool size needed to draw data from. Confidence intervals are used to represent how confident we can be that the results of a sample population reflect results acquired from the entire population. Confidence levels measure certainty and how often the sample population would give the same results if it was sampled numerous times.

For this research study, the 95% confidence level was chosen, as Cohen et al. (2007) suggest this is the most commonly used value by researchers. This was used in conjunction with confidence interval of 7%. The calculation estimated that a total of 120 undergraduates needed to answer the questionnaire and be interviewed during in-class observations, so as to achieve a 95% confidence level for the sampled population.

Figure 6

Higher education student enrolments by subject area in the UK, 2017/2018 (HESA, 2019)

Biological Sciences	233,970
Veterinary Sciences	7,860

For the qualitative aspect of the methodology, there is a need to evaluate the sample size throughout the data collection process, in order to ensure sample adequacy for analysis (Maltreud et al., 2016). It is frequently claimed that in qualitative research the sample size depends on new themes emerging; this focuses on saturation and guides data collection in relation to 'informational redundancy' (Sandelowski, 2008, p. 875), or theories arising as data collection proceeds. Since key themes cannot be identified in advance, the sample size for qualitative research is decided *a posteriori* (Sim et al., 2018). The saturation concept was first mentioned by Galser and Strauss (1990) in Grounded Theory analysis, where newly emerged themes were directly compared to previously acquired ones in order to identify similarities, until there is 'topic exhaustion' where the researcher no longer receives additional information (Maltreud et al., 2016). Maltreud et al. (2016) proposed the concept of information power; this is a model where the research aim, sample specificity, theory, dialogue quality and strategy analysis are used as tools to appraise the sufficiency of the sample size in a qualitative study. The model is by no means used as a checklist to calculate the sample size, but as a recommendation for participants' recruitment; even though the interviews were not typical and lengthy, but rather part of in-class observations. The model is further discussed below (Maltreud et al., 2016).

Study Aims

Initially, according to Maltreud et al. (2016), information power is directly related to the aims' extent of focus: the broader the aim, the more participants should be included, given that the phenomenon of interest is comprehensive.

Specificity of the Sample

The specificity of participants' characteristics depends on the sampling method. A less widespread sample with common features will yield results that are highly specific to the study's aims. For this study, where convenience sampling was used, specificity is high, since all undergraduates had experience of continuous exposure to practical work classes, thus meeting the criteria of the target population.

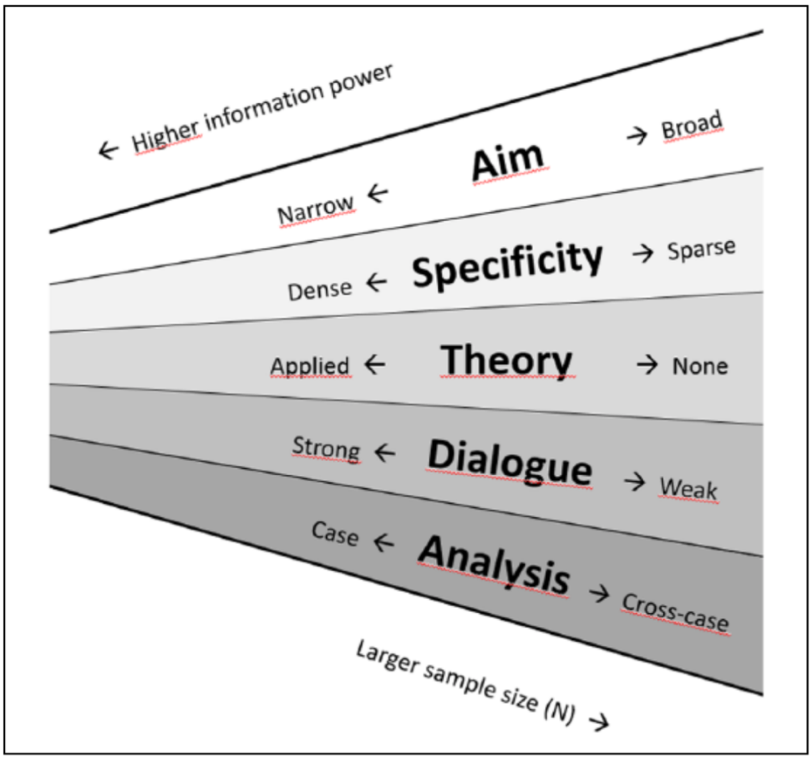
Dialogue Quality

The quality of the dialogue when interviewing participants has a direct impact on the quality of data acquired. Clear and strong communication provides sufficient information from a small-sized population, rather than ambiguous dialogues without focus. The interaction of the interviewer with the participant predicts the quality. As aforementioned, it was beneficial that the researcher was close to the undergraduates' age. In addition, the interviewer had academic qualifications and experience directly related to the subject area from which the sample was drawn, which facilitated the approach.

Strategy Analysis

Information power is directly related to the analysis strategy, where a case study with an in-depth analysis of the selected population requires fewer participants. Use of the information power model proposed by Maltreud et al. (2016) revealed that this study has the possibility of recruiting the least amount of participants if the aims are narrow, the participants are highly specific, it has an already established theoretical framework as a backbone, and the analysis focuses in depth on a case. The researcher aimed to cover the target population in a naturalistic way (Bell, 1987), rather than meeting strict quantitative sampling criteria. This model therefore indicates that "the more information the sample holds, relevant for the actual study, the lower number of participants needed" (Maltreud et al., 2016, p. 1759).

Figure 7
Information power: items and dimensions of the model (Maltreud et al., 2016)



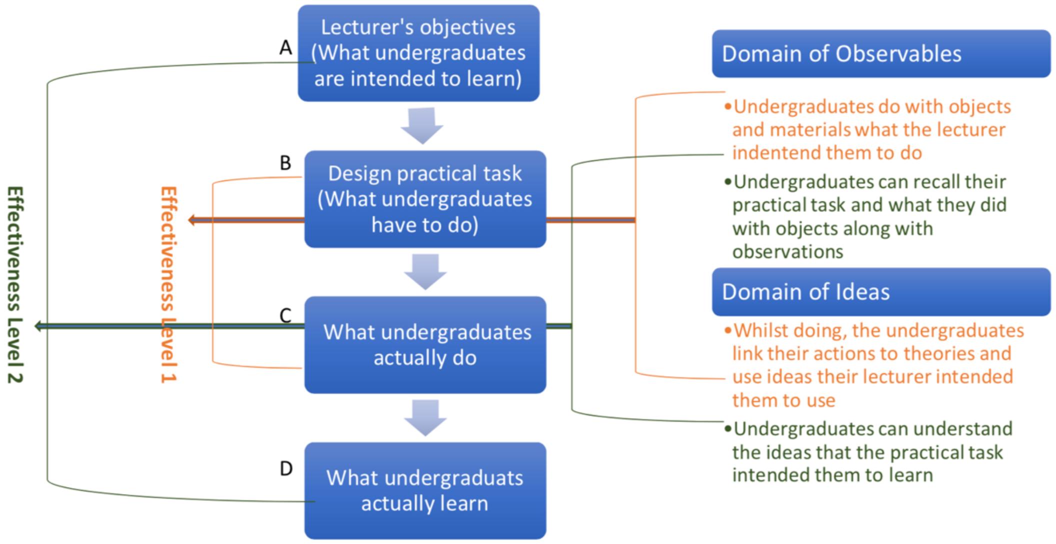
Theoretical Framework

Model of Practical Work Effectiveness

As Abrahams and Millar (2008) explained in their research on whether practical work in secondary school science is effective, it would not make much sense to ask whether practical work is an effective teaching strategy in general, but whether *specific tasks* are effective in relation to the lecturers' aims and objectives in designing the task. For this reason, Millar et al. (1999) designed a framework for evaluating the effectiveness of a task, consisting of two levels of effectiveness, which can be similarly applied to this research with undergraduates at university level. Millar et al. (1999) stated that the researcher should be asking focused questions concerning the effectiveness of *specific* tasks, which as a consequence will assist undergraduates in meeting *specific* learning outcomes and objectives.

Figure 8

Theoretical model for the effectiveness of practical work. Adaptation from Millar et al. (1999) and Tiberghien (2000)



Initially, the lecturer needs to decide on the learning objectives and what undergraduates should learn from the practical task (Figure 8, Box A). Using this model, the objective is to evaluate the effectiveness of a task through the lens of what the lecturer deems as successful based on his/her intentions of what undergraduates need to learn. Then, the lecturer needs to choose the activity that will enable undergraduates to learn what is intended, by designing a task that has the potential to fulfil the learning outcomes (Box B). The next level of the model relates to what the undergraduates actually do (Box C), as this might differ from what the lecturer intended, due to multiple reasons. Undergraduates might have difficulty understanding their practical protocol with instructions, and even if they successfully manage to follow every step, obstacles such as faulty apparatus can consume their time when focusing on non-substantial tasks. The last level of this model refers to what undergraduates actually learn (Box D) as a result of their experience during the practical. Undergraduates might engage with the task mechanically or hands-on, without engaging their minds in the task by using ideas and theory the lecturer had intended them to use in order to understand a specific concept.

The theoretical model demonstrated in this study takes effectiveness into consideration by using two levels to describe what undergraduates do in relation to the lecturer's intentions on learning outcomes. Therefore, 'level 1 effectiveness' refers to the relationship of box B and box C. Box A and box D, as 'level 2 effectiveness', are concerned with what undergraduates learn relative to the intentions of the lecturer. This theoretical framework assists in specifying the research questions, in order to directly focus on whether practical work (based on the specifications mentioned earlier) promotes learning, and is therefore effective.

This model is then linked to Tiberghien's (2000) model of knowledge, combining the domain of observables with the domain of ideas. As a result, Abrahams and Millar's (2008) analytical framework helps in identifying what universities focus on during a practical task by identifying effectiveness in terms of the domains suggested by Tiberghien (2000). Specifically, do lecturers focus on developing scientific knowledge or scientific skills?

As a result of the analytical framework presented by Abrahams and Millar (2008), the effectiveness of a practical task can be evaluated on two levels of effectiveness, which are further divided into two domains: those of observables and of ideas. Modifying Abrahams and Millar analytical model (2008, p. 5), levels are defined as presented in Figure 9.

Figure 9

Analytical framework for the effectiveness of practical work, adapting the domains of knowledge by Tiberghien (2000) and levels of effectiveness by Abrahams and Millar (2008). Modified table by Abrahams and Millar (2008, p. 5).

Learning outcomes	**Domain of observables**	**Domain of ideas**
Level 1 (what undergraduates do)	"the [undergraduates] do with the objects and materials provided what the [lecturer] intended them to do, and generate the kind of data the [lecturer intended]" (Abrahams & Millar, 2008, p. 5)	"whilst carrying out the task, the [undergraduates] think about their actions and observations using the ideas that the [lecturer] intended them to use" (Abrahams & Millar, 2008, p. 5)
Level 2 (what undergraduates learn)	"the [undergraduates] can later recall things they did with objects or materials, or observed when carrying out the task, and key features of the data they collected" (Abrahams & Millar, 2008, p. 5)	"the [undergraduates] can later show understanding of the ideas the task was designed to help them learn" (Abrahams & Millar, 2008, p. 5)

Given the short-term access to the School of Life Sciences, it would not be possible to assess the effectiveness of the domain of observables and domain of ideas at level 2, since the researcher would be unable to evaluate whether undergraduates have a long-term memory of ideas they learned or materials they handled. However, this can be reported, to a limited degree, in interviews, when undergraduates are asked whether they remember anything from previous practical classes.

According to Abrahams and Millar (2008), the only challenge to the analytical model proposed is that "observations are theory-laden" (p. 6), since undergraduates perceive observables through the theory-containing schemata they operate with. However, it is further explained that undergraduates' responses are viewed with a pragmatic lens and are regarded as observational if the response is "quick and decidable" (Abrahams, 2005, p. 69). Abrahams and Millar (2008) explained that to a certain extent, all observations are processed through conceived theories; thus, undergraduates may not necessarily report actual observations of what they see *per se*, but instead a "pseudo-observation" (Abrahams, 2005, p. 69), or a perception of what they see through mentally processing existing knowledge that is either correct or erroneous.

Novak's Theory of Meaningful Learning

According to the theory of meaningful learning, Galloway and Bretz (2015) explained that meaning is created "based on how they [undergraduates] interact with the experience and the context of the experience" (p. 1150). Such meaning depends on how that person thinks, feels and acts. People's actions are usually dictated by their thoughts and feelings about what they are experiencing. Similarly, undergraduates in a laboratory "choose to act (psychomotor) in the lab [depending] on how they think about (cognitive) and feel towards (affective) their laboratory experiences" (Galloway & Bretz, 2015, p. 1150). When undergraduates are in the laboratory they are required to do things. For this reason, if 'doing' is essential, then we need to understand what undergraduates feel and think about/and of practical work, and how they connect thinking and feeling within the context of doing. According to Novak (2010), meaningful learning occurs when emotionally positive feelings emerge, as well as an understanding of the knowledge students are introduced to. Conversely, negative feelings occur when understanding is unclear, or feelings of anxiety, fear and inadequacy emerge. The sharing of positive feelings and thoughts between the learner and the teacher create an educative environment that is successful, and therefore this creates meaningful learning experiences.

The questionnaire designed by Galloway and Bretz (2015) uses Novak's theory of meaningful learning and human constructivism to measure the expectations and experiences of undergraduates in a laboratory within the affective and cognitive domains.

Amongst the three domains integrated within the theory of meaningful learning, the affective (feeling) was the domain of focus in this research study, since motivation and interest, according to Abrahams (2009), is the inner drive to action; this will be discussed next. Indeed, as Novak (2010) explained, feelings or affect can "enhance or impair learning" (Novak, 2010, p. 30).

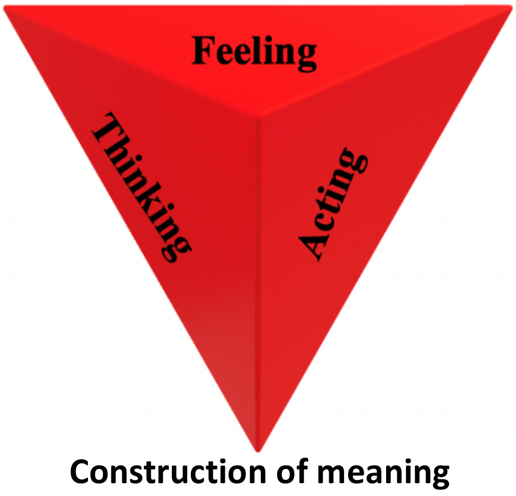
Model of Affective Value for Practical Work

Abrahams (2009) defined motivation as the inner drive to action, and according to Schunk (2012), it refers to a process of initiating and sustaining a behaviour that aims to achieve certain goals. For a highly motivated undergraduate, the subject being studied may be something that he or she is not interested in, possibly due to an external factor such as a reward (Schunk, 2012). For example, someone might be motivated to study science because scientists earn a lot of money, but not because he/she is interested in learning the subject itself. For this reason, when asking whether practical work has an affective value, we should enquire "to do what?".

Undergraduates might be motivated to study science for many reasons, but interest in the subject is not guaranteed. This raises the question: Are undergraduates who are interested in learning sciences intrinsically or extrinsically motivated? According to Maslow's model of the hierarchy of needs, every person's actions represent "a striving to satisfy needs" (Schunk, 2012, p. 364). In order to understand how undergraduates are motivated (if at all) towards practical work and learning sciences, we need to understand the reasons for this. Does the way a practical work lesson is structured satisfy undergraduates' needs, and does it provide them with an environment that enables them to pursue growth and learning? For example, in a constructivism-driven lesson, scaffolding while in the zone of proximal development reinforces positive learner behaviour; and, based on Maslow's model, it motivates learners to enhance their learning (Burleson & Thoron, 2017).

As Novak (2010) explained, the affective value or 'feeling' is an aspect of the tripartite model that contributes to meaningful learning. Therefore, refining the research question, we should ask "Does practical work contribute to meaningful learning, and if yes, to what extent does the affective value contribute to meaningful learning?", and then "If yes, to do what?". According to Galloway and Bretz (2015), people's actions are affected by their thoughts and feelings. Following Novak's theory of meaningful learning (Figure 10) (Novak, 2010), "meaningful learning underlies the constructive integration of thinking, feeling, and acting leading to human empowerment for commitment and responsibility" (p. 18). Undergraduates give meaning to their laboratory experiences based on a combination of how they feel, think and act (Galloway & Bretz, 2015). Affective learning occurs when positive feelings arise during a teaching experience that enhance the person's ability to think, so as to give meaning to an experience (Novak, 2010).

Figure 10
Construction of meanings based on Novak's model of meaningful learning (2010)

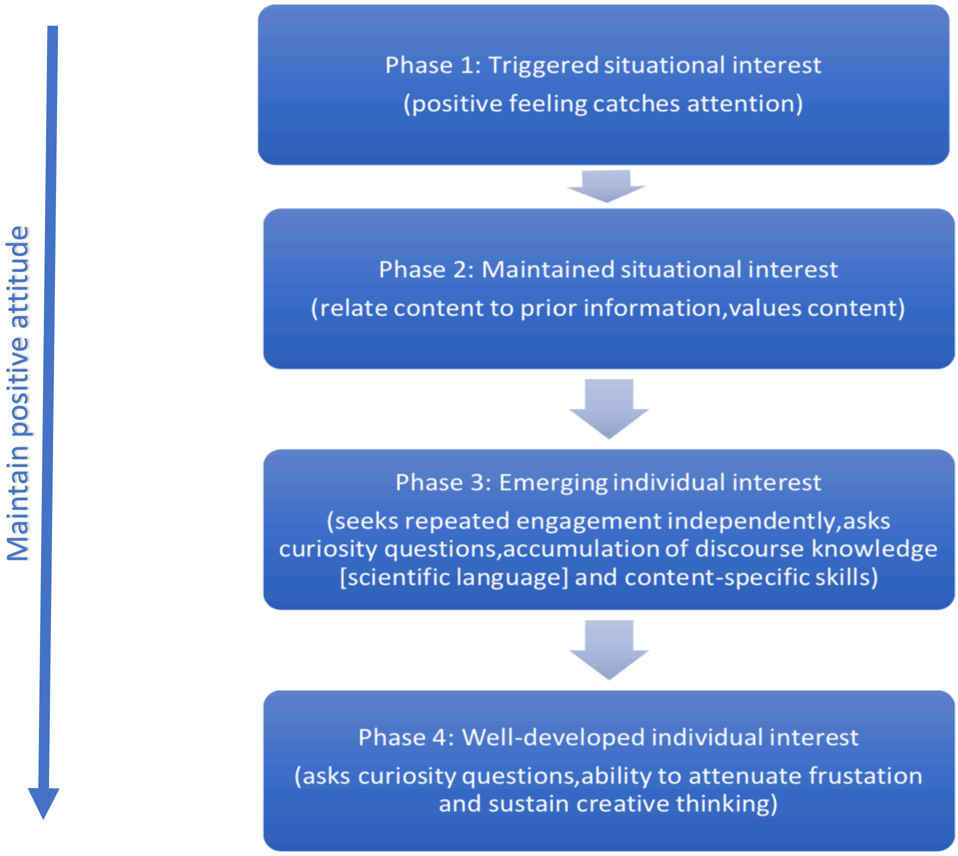


As aforementioned, Novak (2010) stated that meaningful learning occurs when emotionally positive feelings emerge. Positive feelings, in turn, trigger situational interest, as a starting point in the model by Hidi and Renninger (2006) discussed below.

The four-phase model of interest development by Hidi and Renninger (2006) shows that interest influences learning in terms of attention, goals, and levels of learning. According to this model, interest is first triggered by the environment, and is situational. Although not mentioned in the model, the trigger can be either intrinsic or extrinsic motivation towards the subject, in this case practical work. Hence, the first phase of the model is: “Does practical work trigger situational interest?” According to Hidi and Renninger (2006), situational interest triggers someone to desire more information about something; in this case, undergraduates having the desire to actively seek answers, and thus engaging in the practical task. The second phase of the model is “Maintained situational interest”, which involves the persistence and maintenance of interest: this can be affected by instructional conditions and learning environments. It can trigger positive feelings, and through repeated engagement, the interest can emerge. If situational interest has been achieved, it can have long or short duration depending on repeated engagement. If the situational interest is maintained through effort, the interest develops and then starts becoming personal, moving to phases three and four (Hidi & Renninger, 2006). According to Novak (2010), students need to be motivated to learn; otherwise there will be no learning.

Figure 11

Four-phase model of interest development (Hidi & Renninger, 2006)



"Motivation derives from some unsatisfied need or desire on the part of the learner" (Novak, 2010, p. 275), and such needs have cognitive and affective aspects that need to be met. In this way, curricula should be able to carefully create activities where students think and feel.

Positive feelings are built when the student understands information that is taught and can use it further. Consequently, the student feels in control, as meaningful learning contributes to intrinsic motivation, since the knowledge can be further applied to problem solving. In contrast, extrinsic motivation derives from rote learning, where the primary goal of the student is to get a good grade in the assessment (Bretz, 2001; Novak, 2010). According to Bretz (2001, p. 4), "Meaningful learning occurs when education provides experiences that require students to connect knowledge across the three domains [cognitive, affective, psychomotor]". Students must think of concepts, carry out experiments that will allow them to connect prior knowledge of perhaps abstract concepts to what they are doing (minds on – hands on), and make sense of what they are doing, so they can apply the knowledge later on and make sense of what they are doing (feeling positive) .

“The meaning people make of their experience affects the way they carry out that experience” (Blumer, 1969, p. 2); hence, this affective model serves to indicate whether positive or negative emotions contribute to interest and meaningful learning.

Task Characterisation

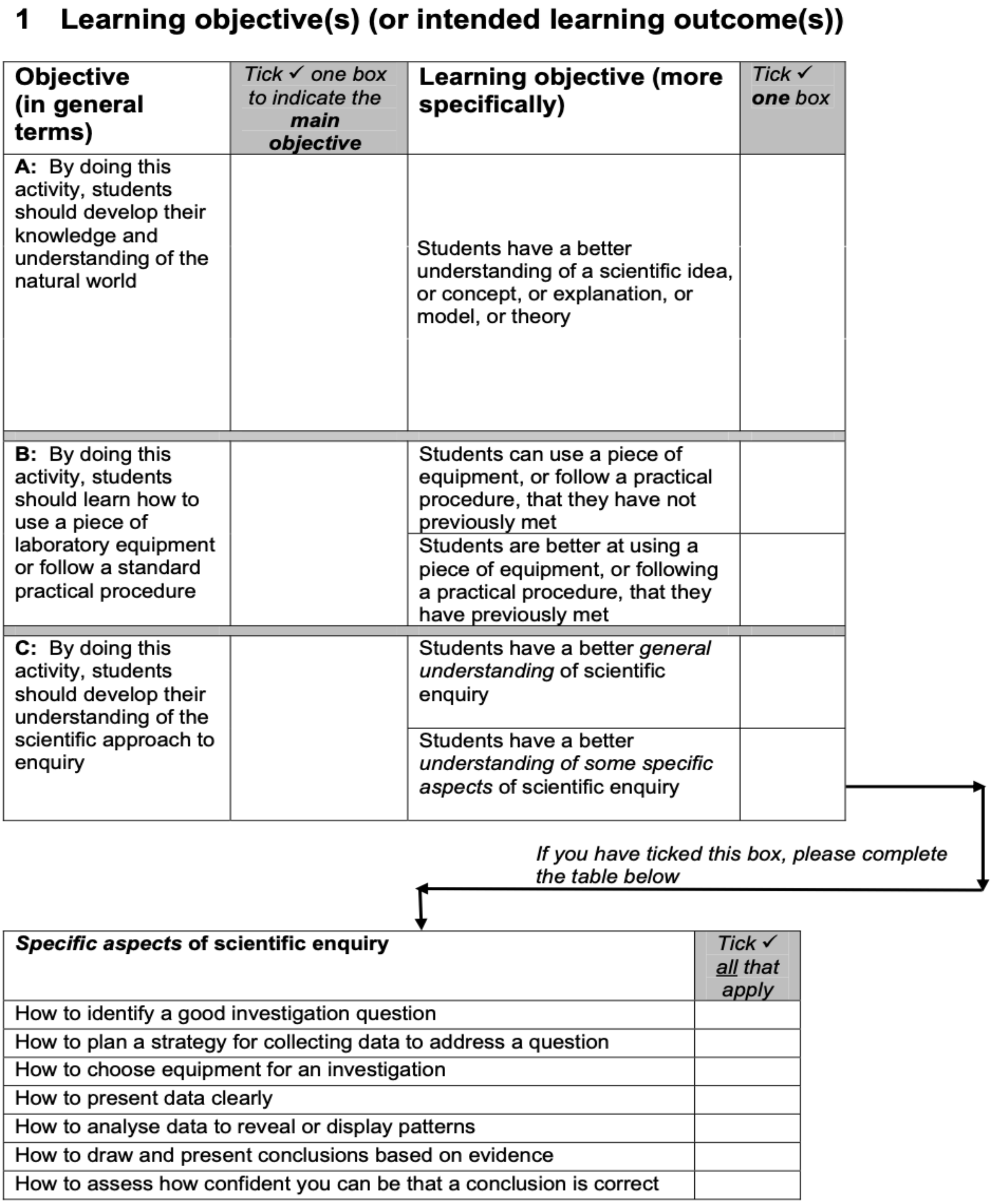
In order to evaluate a practical task, an observation instrument developed by Millar (2009) was used (Figures 12 and 13) to distinguish the intended learning objectives and the design of the actual task. Millar’s observation instrument is a tool designed to help in reviewing how practical work is used in laboratory lessons. It provides a structured approach for examining the effectiveness of practical work by looking on different components of a practical work lesson such as the use of equipment, demonstrations etc. By analysing the elements of a practical work lesson, the aim was to identify areas that contribute in the improvement of lesson’s quality and undergraduates’ learning standards. Additionally, the instrument provided a framework that allowed monitoring between different practical work lessons.

Initially, in order to assess whether undergraduates were doing and learning what the lecturer intended them to do or learn, respectively, the intended objectives had to be recognised. The objectives were classified in three different levels, related to (1) knowledge development, (2) development of skills that undergraduates had either previously gained or not, and (3) development of the scientific approach to enquiry (Figure 8, 1C). These were further expanded, so that the researcher could identify whether there were specific aspects of the scientific enquiry that were part of the learning objectives to be introduced for that specific practical work class.

Furthermore, a list with specific features of the practical work design was used, in order to describe the type of the practical task observed, which would assist the researcher in drawing conclusions about the lesson. The list included features related to the openness or closure of the design, the structure of the activity, and the level of importance of prior scientific ideas required from the undergraduates in order to carry out the activity. Moreover, a list with descriptions of what undergraduates were required to do with ideas and objects assisted in clarifying what the researcher had to observe, to help in assessing whether a practical class was successful or not based on the lecturers' aims. Presentation of information was also recorded, in order to provide details of the way the practical lesson was conducted, such as how the purpose of the study was communicated to undergraduates, how was it explained, whether there was an discussion of information prior or after the practical class, and how undergraduates recorded the activity (notes, worksheet, written report, etc.). At the end, an assessment of the activity's learning demand was required, to provide insights on how much knowledge was required to undertake the practical task. In addition to the observation sheet, the researcher kept a record of what has happening in the lesson and in the laboratory, impromptu comments from undergraduates and the lecturers, and details of anything that was considered useful in order to answer the research questions.

Figure 12

Observation instrument on the structure and design of laboratory activities (Millar, 2009)



1 Learning objective(s) (or intended learning outcome(s))

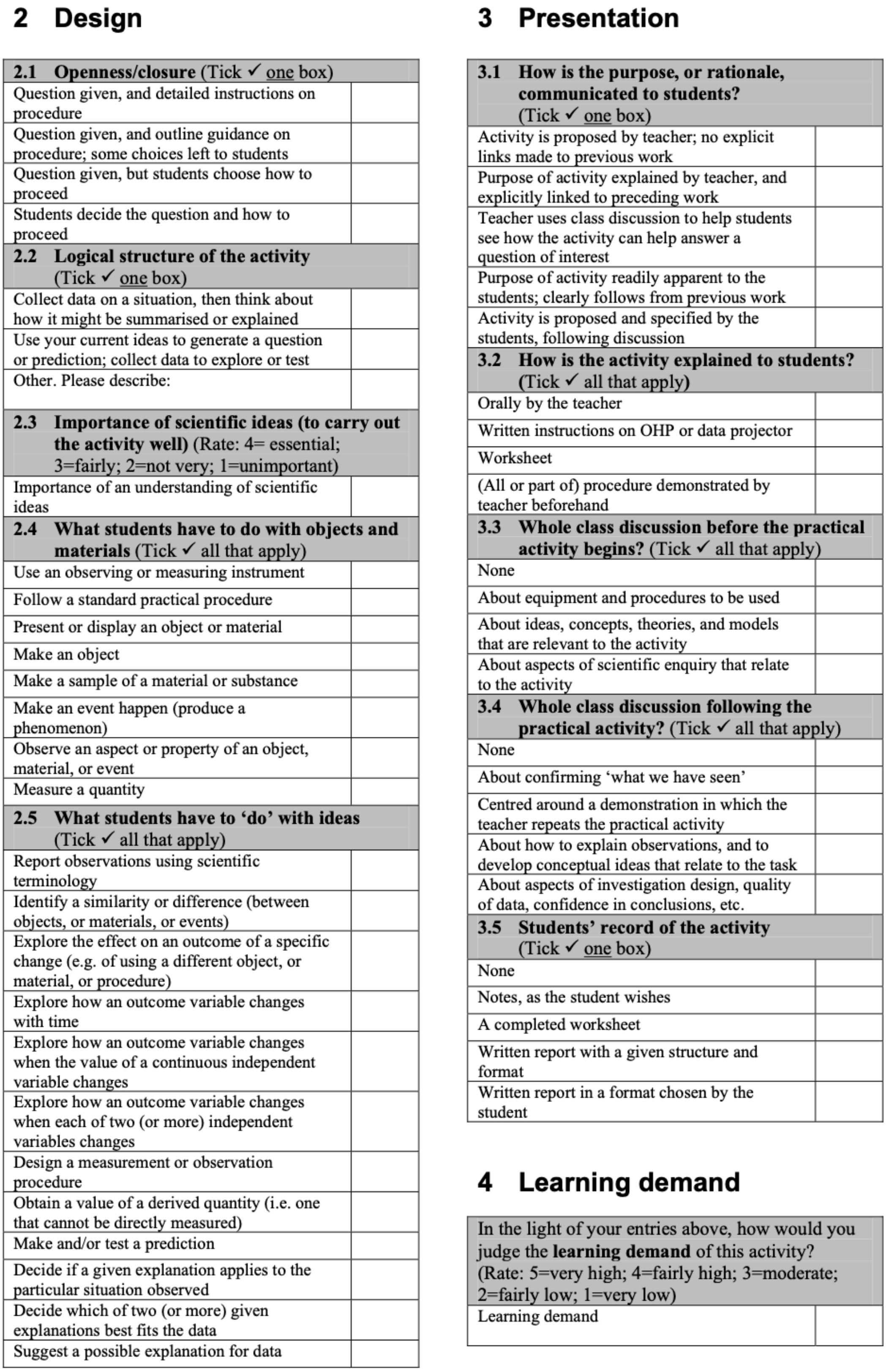
Objective (in general terms)	*Tick ✓ one box to indicate the **main objective***	**Learning objective (more specifically)**	*Tick ✓ **one** box*
A: By doing this activity, students should develop their knowledge and understanding of the natural world		Students have a better understanding of a scientific idea, or concept, or explanation, or model, or theory	
B: By doing this activity, students should learn how to use a piece of laboratory equipment or follow a standard practical procedure		Students can use a piece of equipment, or follow a practical procedure, that they have not previously met	
		Students are better at using a piece of equipment, or following a practical procedure, that they have previously met	
C: By doing this activity, students should develop their understanding of the scientific approach to enquiry		Students have a better *general understanding* of scientific enquiry	
		Students have a better *understanding of some specific aspects* of scientific enquiry	

If you have ticked this box, please complete the table below

***Specific aspects* of scientific enquiry**	*Tick ✓ all that apply*
How to identify a good investigation question	
How to plan a strategy for collecting data to address a question	
How to choose equipment for an investigation	
How to present data clearly	
How to analyse data to reveal or display patterns	
How to draw and present conclusions based on evidence	
How to assess how confident you can be that a conclusion is correct	

Figure 13

Observation instrument on the structure and design of laboratory activities (Millar, 2009)



2 Design

2.1 Openness/closure (Tick ✓ one box)	
Question given, and detailed instructions on procedure	
Question given, and outline guidance on procedure; some choices left to students	
Question given, but students choose how to proceed	
Students decide the question and how to proceed	

2.2 Logical structure of the activity (Tick ✓ one box)	
Collect data on a situation, then think about how it might be summarised or explained	
Use your current ideas to generate a question or prediction; collect data to explore or test	
Other. Please describe:	

2.3 Importance of scientific ideas (to carry out the activity well) (Rate: 4= essential; 3=fairly; 2=not very; 1=unimportant)	
Importance of an understanding of scientific ideas	

2.4 What students have to do with objects and materials (Tick ✓ all that apply)	
Use an observing or measuring instrument	
Follow a standard practical procedure	
Present or display an object or material	
Make an object	
Make a sample of a material or substance	
Make an event happen (produce a phenomenon)	
Observe an aspect or property of an object, material, or event	
Measure a quantity	

2.5 What students have to 'do' with ideas (Tick ✓ all that apply)	
Report observations using scientific terminology	
Identify a similarity or difference (between objects, or materials, or events)	
Explore the effect on an outcome of a specific change (e.g. of using a different object, or material, or procedure)	
Explore how an outcome variable changes with time	
Explore how an outcome variable changes when the value of a continuous independent variable changes	
Explore how an outcome variable changes when each of two (or more) independent variables changes	
Design a measurement or observation procedure	
Obtain a value of a derived quantity (i.e. one that cannot be directly measured)	
Make and/or test a prediction	
Decide if a given explanation applies to the particular situation observed	
Decide which of two (or more) given explanations best fits the data	
Suggest a possible explanation for data	

3 Presentation

3.1 How is the purpose, or rationale, communicated to students? (Tick ✓ one box)	
Activity is proposed by teacher; no explicit links made to previous work	
Purpose of activity explained by teacher, and explicitly linked to preceding work	
Teacher uses class discussion to help students see how the activity can help answer a question of interest	
Purpose of activity readily apparent to the students; clearly follows from previous work	
Activity is proposed and specified by the students, following discussion	

3.2 How is the activity explained to students? (Tick ✓ all that apply)	
Orally by the teacher	
Written instructions on OHP or data projector	
Worksheet	
(All or part of) procedure demonstrated by teacher beforehand	

3.3 Whole class discussion before the practical activity begins? (Tick ✓ all that apply)	
None	
About equipment and procedures to be used	
About ideas, concepts, theories, and models that are relevant to the activity	
About aspects of scientific enquiry that relate to the activity	

3.4 Whole class discussion following the practical activity? (Tick ✓ all that apply)	
None	
About confirming 'what we have seen'	
Centred around a demonstration in which the teacher repeats the practical activity	
About how to explain observations, and to develop conceptual ideas that relate to the task	
About aspects of investigation design, quality of data, confidence in conclusions, etc.	

3.5 Students' record of the activity (Tick ✓ one box)	
None	
Notes, as the student wishes	
A completed worksheet	
Written report with a given structure and format	
Written report in a format chosen by the student	

4 Learning demand

In the light of your entries above, how would you judge the **learning demand** of this activity? (Rate: 5=very high; 4=fairly high; 3=moderate; 2=fairly low; 1=very low)	
Learning demand	

The Research Instrument

The way a research instrument is designed is important, in order to collect information through well-structured questions. By deciding on the type of questions used in the study, one can predetermine, to a certain extent, the type of data retrieved, so they will match the purpose of the study. The most frequently used approaches include open-ended questions stemming from qualitative methodologies, and closed-choice questions based on quantitative methods. An examination of these two approaches follows, to illustrate the reasons for their use in this study.

Closed-choice Questions

As Oppenheim (2000) describes, closed-choice questions are defined as the type of questions where choices are offered to the respondents. Alternatives offered can range from predetermined answers decided by the researcher, replies to dichotomous questions (Yes/No), or choices of preference in a rating scale form. Generally, questions of this type are easier and quicker to answer since no writing is required; this enhances comparability and reduces variability, as respondents are constrained to answer in a similar way and within certain limits (Bryman, 2016). Moreover, since no extensive writing is involved, students' ability to articulate a response does not affect the answer (Wilson & McLean, 1994), and less cognitive effort is required (Peterson, 2000). This means that the tool can be administered rapidly, and respondents are more likely to participate. Closed choice-questions stemming from quantitative methodology practices make the analysis and processing of answers easier, since codes can be used for specific answers, which assists in making direct comparisons among groups (Oppenheim, 2000). Moreover, more questions can be contained in the instrument, as the analysis process requires less effort (Peterson, 2000). However, closed-choice questions inhibit the respondents' freedom to express in their own way; thus, interesting replies are lost if the answers are fixed and predetermined by the researcher (Bryman, 2016). As a result, respondents can become irritated, as answers offered might not be satisfactory to them or represent their views and ideas (Oppenheim, 2000). Furthermore, forcing respondents to reply in a certain way might suggest ideas that the respondent did not have in mind (Oppenheim, 2000). Also, respondents might not make the required effort to answer questions truthfully, to represent reality. Potential limitations include the ballot effect, where if a possible answer is presented, the participants might choose without paying attention to whether the response is relevant or meaningful. Giving an answer adds importance to the question asked, even if the topic of the question is not important to the respondent (Peterson, 2000).

Questionnaires and rank ordering tasks have been previously used in research concerning teachers' and students' beliefs about practical work (e.g., Kerr, 1963; Galloway & Bretz, 2015). In tasks where the respondent needs to prioritise statements and put them in a ranked order, although the researcher has already provided the options, the respondent has the freedom to think and express their preferred ranking order (Cohen et al., 2000). However, if respondents are asked to prioritise a number of items, this makes the task overwhelming and difficult to understand (Cohen et al., 2000). Another approach, that of rating scales, can still provide the researcher with numbers, by converting qualitative responses into numbers while maintaining variability in responses. However, it is difficult to interpret one respondent's 'agree' compared to another's 'strongly agree', as each person perceives things differently and at a different intensity. Moreover, deciding on the number of rating scale categories is important; especially whether there should be a neutral point or not. The second decision to be made when designing a rating scale is the adjectives used to define the categories (e.g. 'strongly agree' to 'strongly disagree').

A widely used rating system is the Likert scale, which usually consists of five categories and a declarative statement, with a list of responses ranging from strongly agree to strongly disagree. Likert scales, according to Novak (2010), have been commonly used to assess expressions of feelings and attitudes. Many studies concerned with practical work in science education have used questionnaires and attitude scales in order to examine opinions on a topic. However, in order to explore what is really happening in the laboratory and avoid reproducing the rhetoric, open-ended questions stemming from qualitative methodologies were also used, in order to provide more detailed descriptions of what is happening during a practical work lesson. Interviews, for example can validate the responses the Likert scales, to ascertain whether respondents' answers and beliefs match the reality.

Open-ended Questions

Open-ended questioning allows respondents to express themselves freely and in their own terms; this often refers to questionnaires with open-ended questions that have no answering restrictions, or perhaps interviewing methodologies. During interviews, participants are commonly audio or video recorded, and data are transcribed subsequently.

Interviews, according to Seidman (2006), help undergraduates reflect on their experiences in depth, enabling them to tell the stories they hold in their minds, as a way of expressing their subjective reality and the way they perceive their lived experience. Furthermore, interviewing explains the participants' behaviour, in the context that the researcher is observing in a natural setting. As a result, this can ensure that the participants' answers are authentic, or at least more authentic than answers given in closed-choice questions where there are constraints (Cohen, 2007). A disadvantage of interviews is that they are not comparable, in the sense that respondents' fluency and articulation can contribute to the quality of the answer given, and may vary between participants (Cohen, 2007). The analysis of the responses is the responsibility of the interpreter, who examines the subjective experience of the respondent through a subjective lens of the life situation observed (Devetak et al., 2010). Interviews can be conducted in a semi-structured conversation format, where the researcher attempts to prompt participants to answer some predetermined open questions conversationally, giving participants the opportunity to express freely, without constraints (Longhurst, 2003). However, interviews are usually time-consuming, as respondents get carried away with time. Moving to the analysis of responses, coding answers is challenging, as emerging topics have to be categorised. Transcription of interviews takes time and is costly, and audio recording raises ethical concerns as the researcher will have to maintain the participants' anonymity and confidentiality, as well as safety during data handling and storage (Bryman, 2016).

Different methods are required for different purposes in research. Qualitative methodologies assist in exploring respondents' understanding of the reality on the spot, as well as capturing unique views that might have been lost had the researcher decided to use closed-ended questions. Furthermore, Novak (2010) described interviewing as one of the most powerful ways of identifying students' feelings. Studies have combined both quantitative and qualitative methodologies, with a mixed-methods approach of using both closed and open-ended questioning methods, so as to cross-validate responses and determine whether they represent the reality.

The Research Questioning Method

It has become clear that both qualitative and quantitative questioning approaches carry their advantages and disadvantages. Hence, a mixed-methods approach with a combination of these questioning methods can prove beneficial for the study; despite the fact that both methods stem from different ontologies and epistemologies, as quantitative methodologies have been linked to positivism and qualitative to interpretivism (Ritchie & Lewis, 2003).

The quantitative methodology was used to investigate undergraduates' beliefs before and after experiencing practical work, to discover whether they had positive or negative views towards their learning experience. Quantitative and qualitative methodologies were combined in order to investigate lecturers' opinions on practical work, along with undergraduates' understanding of scientific concepts and perceptions on the affective value of practical work.

Undergraduates participated in a series of semi-structured discussions during the observations; they were also administered a pre- and post- paper-and-pen questionnaire, at the beginning and end of the semester respectively, so as to state their expectations of what laboratory work should be like and whether those expectations had been fulfilled. Lecturers participated in one-on-one semi-structured interviews, and were also given two activities where they had to put in ranking order their perceived purposes of practical work for each academic year (Years 1, 2, 3), along with describing the laboratories where they taught for each year, based on student responsibility (confirmatory laboratories, structured inquiry, guided inquiry, research-based inquiry).

Undergraduates Questionnaire and Interviews

In order to answer the research questions, a 34-item questionnaire (MLLI) was given to the undergraduates, in order to answer the research questions of this study. The questionnaire used was a modification of Galloway and Bretz (2015) (the first 31 questions), and included a four-point scale with categories starting of 'Strongly disagree (1)', 'Disagree (2)', 'Agree (3)', and 'Strongly Agree (4)', with no midpoint included. An even-numbered Likert scale with no neutral choice was used to produce an ipsative or forced choice, which would allow the researcher to clearly understand whether responses were negative or positive towards practical work (Bertram, 2007). Garland (1991) stated that midpoints in questionnaires can contribute to the distortion of data, as the participant will be biased in the sense that certain responses can be given so as to look acceptable or desirable. Even though the original MLLI instrument used a slider bar for respondents to indicate their percent agreement with each statement it was decided that the authors initial Likert Scale approach was preferred. Slider bars have limitations including the respondents' difficulty in choosing answers from a large range of values on the scale, a misinterpretation of the scale and as a result challenges in accurately measuring the difference between responses in the analysis phase (Liu & Conrad, 2019). Concerning the questions, some were phrased in different ways, to check how valid the responses were (e.g.: "Got stuck but kept trying" and "made mistakes and tried again"; or "feel comfortable when using equipment" and "feel anxious when using equipment"). Additionally there was a question to test whether undergraduates were reading the questions. According to Galloway and Bertz (2015), the questionnaire was designed in order to measure undergraduates' expectations and experiences in the cognitive and affective domain of learning. In order to measure expectations of undergraduates, the questionnaire was administered on the first semester prior to their first laboratory class. Then the second part of the questionnaire was administered at the end of the semester, so that undergraduates could reflect on their experiences. The items remained the same from pre-test to post-test, but the verb tenses were modified from the future tense (describing expectations) to the past tense (describing experiences). The initial questionnaire from Galloway and Bertz (2015) included chemistry terms that were modified, without changing the meaning of the question, to life science terms, so as to fit the purposes of this study.

One question concerning data collection was deleted, as it was not appropriate to the practical lessons observed, and three extra descriptive questions were added to the questionnaire, for further understanding that would help to answer the research questions.

The use of questionnaires for the purposes of this research study is advantageous due to their strength of being able to quickly and inexpensively collect and provide data from large samples to get a representative image of their characteristics as well as being versatile to be used by different kinds of people (DeCarlo,2018). Moreover questionnaires are a flexible methodology as they provide respondents' anonymity and capture easily analysable and interpretable data (DeCarlo,2018). Additionally, the questionnaire designed can be used to assess the topic of interest over time, allowing for tracking of changes in thoughts and attitudes due to a questionnaire's standardised nature and reliability; assuming that questions are well constructed (DeCarlo,2018)..

As with all methodologies, questionnaires come with certain drawbacks which can be counter-balanced if the surveys are first piloted to ensure that the phrasing is not confusing to respondents (Bartram,2019). Questionnaires can also be problematic in terms of lack of depth as questions are usually general and cannot capture detailed information nor non-verbal information such as expressions or body language (Bartram,2019). However, ensuring that the questionnaire is structured in a way to cover different perspectives of the same topic allows for more accurate results. Last but of considerable significance is the need to motivate respondents to respond to the questionnaires (Bartram,2019).

Table 7

Item classification (Modified questionnaire (Questions 1–30) from Galloway and Bretz (2015). Items are classified based on meaningful learning (C=COGNITIVE, A=AFFECTIVE, C/A=COGNITIVE/AFFECTIVE) and how the item affects meaningful learning (+ = positive contribution to learning, - = negative contribution to meaningful learning)

1 C/A +	Learned science that will be useful in my life.
2 A -	Worried about finishing on time.
3 C/A-	Felt unsure about the purpose of the procedures.
4 C+	Experienced moments of insight.
5 C -	Was confused about how the instruments work.
6 C+	Learned critical thinking skills.
7 A+	Was excited to do science.
8 A -	Was nervous about making mistakes.
9 C+	Considered if my data makes sense.
10 C+	Thought about the function of Humans/animals/plants/cells/atoms/molecules.
11 C/A-	Felt disorganised.
12 A+	Developed confidence in the laboratory.
13 C/A-	Worried about getting good data.
14 C-	Thought the procedures to be simple to do.
15 C-	Was confused about the underlying concepts.
16 C+	“Got stuck” but kept trying.
17 A-	Was nervous when handling chemicals/samples.
18 C+	Thought about science I already know.
19 C/A-	Worried about the quality of my data.
20 A-	Was frustrated.
21 C+	Interpreted my data beyond only doing calculations.
22	This statement is used to discard the survey of people who are not reading the questions. Please select strongly disagree for this question.

23 C-	Focused on procedures, not concepts.
24 C+	Used my observations to understand the behaviour of humans/animals/plants/cells/atoms/molecules.
25 C+	Made mistakes and tried again.
26 C/A+	Was intrigued by the instruments.
27 A-	Felt intimidated.
28 C-	Was confused about what my data mean.
29 A+	Was confident when using equipment.
30 C+	Learned problem solving skills.
31 C+	Understood theory better through practical work.
32 C/A +	Gained practical experience for future jobs.
33 C+	Could recall and remember concepts because of practical work.

Furthermore, an additional item concerning the affective value was added to the questionnaire in the form of a dichotomous question, in order to understand whether practical work had any effect on extrinsic and intrinsic interest of students.

34. Is practical work the reason you want to (circle your choice) :

- Pursue a job in sciences? **Yes No**
- Study for a postgraduate degree in science? **Yes No**
- Engage with science in your free time (watch science programmes, read scientific magazines, discuss about science)? **Yes No**

The questionnaire was used as a quantitative tool in order to examine undergraduates' views and whether there were more positive or negative attitudes towards practical work; according to the aforementioned affective model, this plays an important role in building either situational or individual interest.

Undergraduate Interviews on Effectiveness at Levels 1 and 2

Undergraduate semi-structured interviews were carried out in order to explore the effectiveness of practical work in the two aforementioned levels. Before the interviews, the researcher consulted the lecturers and teaching technicians so as to understand what the aims of the practical were, and what they wanted the undergraduates to achieve. The researcher was deemed authorised to interview life science undergraduates on conceptual elements, as she held qualifications including a bachelor's degree and a master's degree in life sciences/biomedical sciences, as well as relevant working experience in the field.

The undergraduates were initially interviewed to examine whether they were cognitively engaging with the experiments while working in the laboratory. The experiment protocol was thoroughly studied beforehand, and with the help of the lecturers, the researcher asked undergraduates probing questions about the background theory underlying the experiment, to assess whether they understood what they were doing. These could range from questions concerning the scientific theory to questions about different technical procedures they were doing, and whether they understood the reason behind those actions. Also, undergraduates were interviewed and observed to discover whether they could do what the lecturer expected them to do (e.g. pipetting, handling equipment, extracting DNA). Lastly, undergraduates were interviewed to explore their feelings and thoughts about practical work and whether they were enjoying it. Cohen (2007) explained that interviewing someone in person has a higher response probability where participants can elaborate on their thoughts. Even if the undergraduates do not reply explicitly to the open-ended questions, there is always the opportunity to probe in order to acquire better explanations and clarifications of what they are thinking. In this study, interviews with the undergraduates were important for revealing what was happening in the laboratory, because usually (as discussed previously), questionnaires usually repeat the rhetoric, because respondents answer questions that do not necessarily meet the reality. Therefore, interviewing participants in this study helped to collect their on-the-spot responses.

In addition, it was deemed necessary to observe how undergraduates were working in the laboratory, to see their weaknesses and strengths, and reasons why they might respond in a negative or positive way. Undergraduates interested in participating in the study were interviewed both individually and as pairs (with their laboratory partner), engaging in a casual conversation. Whenever a member of the dyad dominated the discussion, an opportunity was given to the other person to discuss and reflect.

In order to encourage undergraduates to respond in a casual way without fearing that they were being examined, the study was thoroughly explained to them, as part of the ethical requirements, as well as the background of the researcher. This made them understand that the researcher was not interested in whether their answers to the scientific questions were wrong or correct.

The strengths of using oral interviews as a means of informally assessing conceptual understanding include the ability to assess the undergraduates' knowledge of the subject in a more in-depth but impromptu manner that a written pen-and-paper test (Huxham, Campbell & Westwood,2012). Additionally, interviewing in order to capture an idea of the undergraduates' conceptual understanding can also assess their ability to draw conclusions something indicating skills of reflecting in contrast to rote learning (Huxham, Campbell & Westwood,2012).. However, testing understanding from oral interviews has the potential for bias as it is up to the interviewer's perception to accept a question as right or wrong. However even though there is a subjective element in assessing undergraduates' understanding of a concept, in this case the interviews were based on simple questions on biological concepts and mechanisms whose assessment is based on objective standardised answers (Huxham, Campbell & Westwood,2012).. Most importantly, at the time of the interview undergraduates might lack focus due to distractions or find it difficult to provide answers on complex topics in a short amount of time (Huxham, Campbell & Westwood,2012)..

Figure 14 *Non-subject specific questions posed to the undergraduates*

- Do you understand how to do this? (Cognitive)
- What do you expect the results to be, based on the information already given? (Cognitive)
- Do you like practical work? Why is that ? (Affective)
- Do you think the experiment is fun? Do you prefer practical work or lectures? (Affective)
- Does this help you understand the theory? How so? (Cognitive)
- What is good about practical work? (Affective)
- Do you know why you are doing this? What is it showing you? (Cognitive)
- What do you understand from this? (Cognitive)
- Are you just following instructions? (Cognitive)
- Do you understand the definitions? (Cognitive)
- Can you explain to me the reading that you got? (Cognitive)
- What is it that makes you like the subject? Is it practical work? (Affective)
- What have you learned from this practical? (Cognitive)
- Will you remember to do this procedure again or will you need to follow instructions again? (Cognitive)
- Do you understand what each step means? (Cognitive)
- Can you please show me which pipette you will use for this? (Doing)
- What is the reading that you got for this? Was it expected? (Doing)
- Can you show me how you set up this equipment?

Staff Members Questionnaire and Interviews

Lecturers and technical staff attending the observed laboratory classes, who were interested in participating in the study, were interviewed at their convenience after the lesson. The interviews were based on a semi-structured approach, where the researcher would ask some questions and let the interviewee lead the conversation by responding and reflecting on the researcher's thoughts. Members of staff interviewed were also asked to reflect on the laboratory lesson observed, in order to answer their questionnaire.

The questions asked included the following:

Figure 15

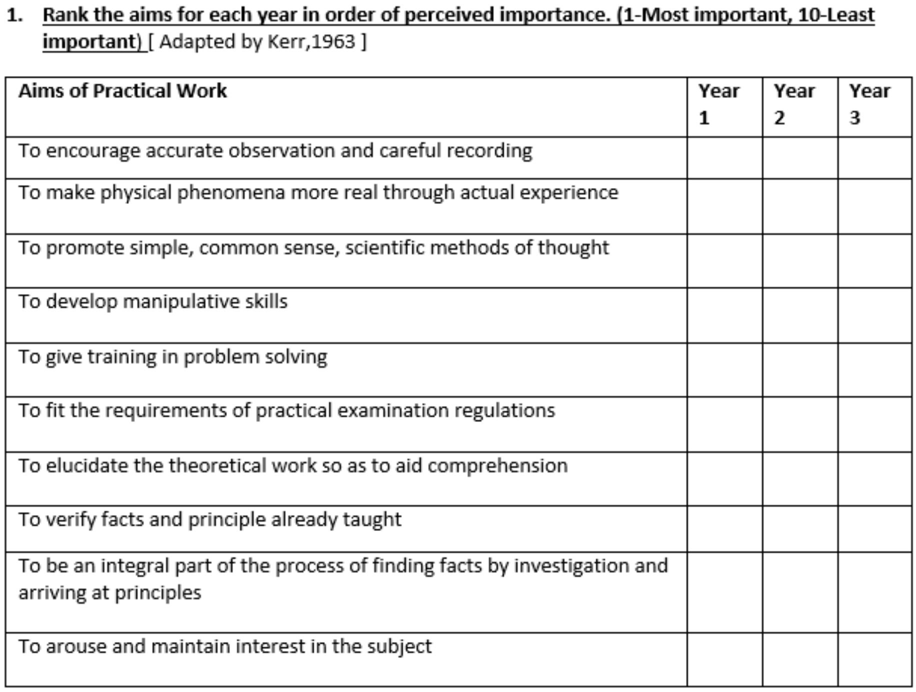
Sample questions from interviews with members of staff in the School of Life Sciences

- Why did you choose to do the practical that I observed?
- Do you think this practical task is an effective way of teaching the concept you wanted to teach?
- Would non-practical work be easier? Did you really need the laboratory or could you have done this as a case study using a computer?
- Is lab work effective as an activity on its own?
- Do you think the practical class I observed was successful? What does a successful practical lesson look like?
- How do you believe practical work benefits undergraduates in general?
- What is it that you want them to learn? Do you think that the actual practical per se helps them to develop conceptual understanding of a topic? What do you want them to achieve when doing one?
- Would you say that laboratory work is something to be done complementary with lectures?
- Would you imagine learning would be affected if there were no practical work sessions? In what way?
- Do you introduce the topic before the practical lesson? Do you upload the content beforehand?
- Are there any learning requirements for your practical lessons?
- Is practical work effective in enabling undergraduates to do what you intended them to do? If yes, how do you assess it ?
- Is practical work effective in enabling undergraduates to learn what you intended them to do? If yes, how do you assess it?
- Does practical work have an affective value for undergraduates? If so, in what way? How do you know it?
- Why do members of staff want more practical work? Does practical work, work? How do you know? And if yes, why would you need to do more practical work lessons if they already work the way they are?

To answer the questionnaire, members of staff were kindly asked to complete one activity. They were required to rank the aims for each year in order of perceived importance; this activity was adapted from Kerr (1963). The activity was included in this study in order to find out what the lecturers prioritised in the laboratory work curriculum, and what aspects of practical work they deemed most effective in each year. Kerr's aims of practical work, albeit dating back to 1963 still resonate today as they can be used to inform the design of science curricula in an attempt to provide education that is both relevant and practical for the science industry. Kerr's empirical work was extended by several key studies (Abrahams & Saglam, 2011; Beatty & Woolnough,1982; Thompson,1975) in the area of practical work and subsequent national and international studies , despite not making direct comparisons, are broadly in agreement with the aims suggested from Kerr's national survey (Johnstone & Al-Shuaili,2001). This study followed Abrahams and Saglam's (2011) initiative in examining whether there had been changes in the importance of science educators' aims' since Kerr's (1963) national survey, but applied those aims in tertiary education. As previously mentioned in the literature, it has been argued that practical work aims in tertiary education incorporate similar themes to those associated with secondary school practical work (Brown & Atkins, 1988; Kirschner & Meester, 1988; Trumper, 2003; Khoon, 2004; Wang, 2005). The National Council of Educational Research and Training (2006) proposed that the pedagogy should focus on skills, cognition and exposure to the nature of science, goals falling into the categories suggested by Shulman and Tamir (1973) which coincide with Kerr's. For the reasons mentioned along with the fact that Kerr's aims align with the theoretical framework used regarding Novak's (2010) affective, conceptual and psychomotor domains as well as Abrahams & Millar's (2009) domain of observables and ideas, Kerr's instrument was regarded as relevant and applicable for the purposes of this study.

Figure 16

Questionnaire for members of staff (lecturers, technicians) in the School of Life Sciences



1. **Rank the aims for each year in order of perceived importance. (1-Most important, 10-Least important)** [Adapted by Kerr,1963]

Aims of Practical Work	**Year 1**	**Year 2**	**Year 3**
To encourage accurate observation and careful recording			
To make physical phenomena more real through actual experience			
To promote simple, common sense, scientific methods of thought			
To develop manipulative skills			
To give training in problem solving			
To fit the requirements of practical examination regulations			
To elucidate the theoretical work so as to aid comprehension			
To verify facts and principle already taught			
To be an integral part of the process of finding facts by investigation and arriving at principles			
To arouse and maintain interest in the subject			

Data Analysis

There are six sources of data in this study: (1) questionnaire data from members of staff (Kerr's questionnaire), (2) laboratory observations, (3) informal undergraduate assessment of skills and conceptual understanding, (4) undergraduate interviews on affective value of practical work, (5) interviews with members of staff, and (6) questionnaire data from undergraduates (meaningful learning). Discussions with members of staff and undergraduates, along with observation notes from each practical work lesson, produced a large volume of data. For this reason, data had to be carefully selected and presented so as to show the main findings. As Fotou (2014) explained, the challenging part of presenting qualitative findings is to decide the volume of data that should be used, in order to prevent "word overload" (Miles & Huberman, 1984, p. 56); this occurs as a result of excessive information that does not necessarily enable the reader to understand the meaning of the data (Fotou, 2014). Findings presented should give answers to the research questions and allow the researcher to communicate clearly the interplay of ideas and findings. Ultimately, as Reid (1978) argued, research is not about the collection of data, if on paper the interpretation and communication of those data are implicitly requested to be made by the reader rather than the researcher.

Kerr's Questionnaire: Aims of Practical Work

The Kerr's questionnaire data were obtained from contributions of 14 members of staff; these results were tabulated, and the rank of each aim for each Year (1, 2, 3) was calculated based on the frequency of responses for each rank. The aims were then presented in order of importance for each year of the undergraduates' three-year degree programme in life sciences.

Laboratory Observations

The laboratory observation instrument designed by Millar (2009) was used to record the features of each practical work lesson in the laboratory. Data acquired from 18 laboratory observations were merged together, and present the number of lessons meeting certain characteristics. In addition, apart from the observation instrument, appropriate non-audible actions and behaviours were noted down as part of observation field notes.

Informal Assessment of Practical Work Effectiveness

The assessment of the effectiveness of practical work was guided by Abraham and Millar's (2008) analytical framework, adapting the domain of ideas and domain of observables.

For effectiveness at level 1, which concerns what undergraduates 'do' with observables and ideas, undergraduates were assessed on their ability to do what the lecturer intended them to do with equipment and materials, along with their capability to use taught ideas while carrying out tasks. The researcher made individual evaluations of undergraduates' skills in using equipment, carrying out procedures, following instructions and observing the intended outcome, while walking around the laboratory during observations, and an overall evaluation of undergraduates' abilities was recorded. Due to the nature of practical work activities, undergraduates have to be 'hands-on' the entire lesson; therefore, they were required to demonstrate their skills throughout the lesson. For this reason, it was decided not to quantify each undergraduate's competence based on on-the-spot observations, as successful performance was not necessarily reflected in a single correct action (e.g. taking a precise measure of a liquid) but in their overall ability to finish the entire experiment and acquire the expected results. For this reason, informal evaluation of skills was obtained by an overall class assessment of whether they could or could not perform as intended while doing an experiment.

For effectiveness at level 2, undergraduates were informally assessed on whether they understood the ideas and theories behind what they were doing, as well as whether they could recall what they previously did with observables and ideas. Correct answers from each undergraduate were tallied and a percentage was calculated. Undergraduate percentages were assigned to three categories (‘most’, ‘some’, ‘only a few’), with ‘most’ indicating the majority (51–100%), ‘some’ indicating 26–50%, and ‘only a few’ meaning 0–25% of the class.

Undergraduates and Staff Members Interviews

Interviews from undergraduates and members of staff involved the transcribing of raw data and processing in a qualitative data analysis software package called Nvivo (QSR International, 2020). Data were assigned to codes and were organised thematically in order to identify topics that arose during interviews. This qualitative analysis will draw on these interviews in order to further understand perceptions and how they are reflected in undergraduates’ laboratory performance, as well as in the way members of staff designed and taught the practical work lesson. The coding process, as described in the literature (Braun & Clarke 2019,2006; Roberts,Dowell & Nie, 2019) involved the familiarisation with the interview script, where the researcher read through the material. During this process, notes were taken on common words, phrases and themes identified. This allowed for the identification of potential codes which were used to organise the script for further analysis as well as aiding in the better understanding of the data, something useful for the contextualisation of the analysis. During the process of coding, meaningful and relevant data were identified and a codebook was created on the software chosen (NVivo) documenting the codes assigned, something that ensured accuracy and consistency throughout the analysis. Similarities and patterns were then detected in the codes assigned so that potential themes could be identified while looking for connections or perhaps inconsistencies between the data. Comparing the themes together ensured that they were not overlapping and themes were later split in order to create cohesion so as to best represent the interview script as a whole. Assigning names to the themes was the last step ensuring that they were meaningful and descriptive.

Undergraduates Questionnaire on Meaningful Learning

Data acquired from the questionnaires were tabulated using the statistical software SPSS (IBM, 2020), in order to analyse them descriptively and inferentially. Year 1 pre-tests were compared to Year 2 pre-tests, to assess undergraduates' expectation difference in one year. In addition, Year 1 pre-tests were compared to Year 2 post-tests at the end of the semester, to evaluate whether undergraduates' experiences surpassed expectations after 16 months of practical work. Finally, Year 2 pre-tests were compared to Year 2 post-tests to assess whether undergraduates' expectations were fulfilled after four months. The questionnaire items were of Likert-scale type, with the derived results considered as ordinal data, since they measure non-numeric concepts (expectations) whose intervals cannot be assumed to be equal (Jamieson, 2004). Methodologies on how to analyse interval data indicate that calculating the mean would not be appropriate for this type of data, as the numbers in the Likert scale represent verbal statements and not numbers (Gravetter et al., 2020; Jamieson, 2004; Wright & London, 2009), revealing the tendency towards a positive or negative perspective overall. The median and mode are deemed as more appropriate measures of "central tendency" (Jamieson, 2004, p. 38). Ordinal data, in this case from Likert scales, cannot be assumed to follow a normal distribution (Fagerland, 2013; Norman, 2010), which is an assumption for parametric tests, as values are highly skewed and either bound to the left or to the right (Kim & Park, 2019). If the assumptions of parametric statistical tests are violated, they could yield erroneous results, as a the wrong type of test will be less powerful and can result in a possible false-negative result (Skovlund & Fenstad, 2001). For this reason, a non-parametric test was more appropriate. In this research, the aim is to test for differences between the questionnaires which were completed at different phases throughout the term, and among undergraduates. Since one of the samples concerns two sets of paired measurements (Year 2 pre-test and Year 2 post-test), the non-parametric alternative of a paired t-test, the Wilcoxon matched pairs test, was used (Figure 14). For the rest of the data (Year 1 pre-test / Year 2 pre-test and Year 1 Pre-test / Year 2 post-test) the non-parametric alternative test to a two-sample t-test, a Mann–Whitney U test, was deemed as appropriate (Gignac et al., 2016). All data were computed with a 95% confidence interval.

Figure 17

Statistical non-parametric tests appropriate for the analysis

Year 1 Pre-test	**Year 2 Pre-test**	Mann–Whitney U test
Year 1 Pre-test	**Year 2 Post-test**	Mann–Whitney U test
Year 2 Pre-test	**Year 2 Post-test**	Wilcoxon matched pairs test

According to Gignac (2016), there is a common misconception that non-parametric tests do not have assumptions, but in fact they do, apart from excluding normal distributed data. A Mann–Whitney U test requires data to follow a similar distributional shape, and thus, as previously mentioned, an implied homogeneity of variance, which means that the dependent variable data are distributed the same way across the two groups (Gignac, 2019; Maxwell & Delaney, 1990). For this reason, a Levene's test (Table 8) was undertaken to confirm homoscedasticity (equality of variances) before proceeding with the analysis of the data. The Levene's statistic was based on the median, as it has been reported that it performs the best with skewed distributions (Brown & Forsythe, 1974).

Table 8

Equality of variances (Levene's test)

Data	Levene's statistic based on median	Sig.
PreCognitiveY1Y2	1.417	0.235
PreAffectiveY1Y2	2.321	0.129
PreCog/AffY1Y2	0.714	0.399
PreY1postY2Cognitive	0.691	0.406
PreY1postY2Affective	1.152	0.284
PreY1postY2Cog/Aff	3.452	0.064
PrePostY2Cognitive	0.148	0.700
PrePostY2Affective	0.884	0.348
PrePostY2Cog/Aff	1.718	0.191

With significance values larger than 0.05 in all cases, it can be concluded that the null hypothesis of equal population variances cannot be rejected. The aforementioned data assume equal variances, have a skewed distribution, and their sample size is unequal. Therefore, the appropriate test to choose would be a Mann–Whitney U test and a Wilcoxon ranked test (Skovlund, 2001). The mean score of questions belonging to a specific domain (Cognitive, Affective, Cognitive/Affective) was calculated for each student. The analysis of the non-parametric data for the questionnaires involved the use of Mann–Whitney U and Wilcoxon matched pairs statistical tests. Before proceeding with data analysis, all negatively-keyed items (Q2, 3, 5, 8, 11, 13, 15, 17, 18, 19, 20, 27, 28 in Table 7) were reverse-scored, so that a high score would indicate a positive belief towards meaningful learning. The following formula was used to recode the items (Hanover College, 2022).

Highest value + lowest value – selected response

Validation and Reliability of Data

Triangulation of Study

In this study, data were acquired from multiple sources, as it has been previously mentioned that questionnaires alone usually repeat a rhetoric, and respondents' answers do not necessarily meet the reality (Abrahams & Millar, 2008). Consequently, the triangulation method was used in order to reach a higher level of external validity, as advocated by Cohen et al. (2002) and Yin (2003); it also enabled the researcher to present results from different perspectives (those of undergraduates, members of staff, and researcher's observations) and challenge the findings. Thurmond (2001) explained that this methodological approach allows the elimination of bias, and the elucidation of areas that might have not been prominent had the researcher used a single methodological approach. In addition, triangulation enables the researcher to check the validity of the data by using different primary sources.

Intercoder Validation of Interviews

Thematic analysis of qualitative data acquired from interviews can be challenging due to the difficulty of determining the trustworthiness of the data. For this reason, demonstrating rigour can help increase the validity of results and therefore their potential replicability (Roberts et al., 2019).

First, after the interview transcription initial themes were identified, codes were applied to the qualitative data until a theme saturation was reached. Codes were clearly defined, and additional analysts were invited to review the themes and check the way they were interpreted. The intercoder testing involved the distribution of interview scripts, and a codebook with clearly defined codes, to three doctoral data analysts who attempted to assign the interviewees' responses to the codes. Results from the intercoder testing were reviewed and compared to the researcher's initial coding, using the formula below (Roberts et al., 2019):

Reliability = number of agreements / number of agreements + disagreements

The minimum percentage to demonstrate adequate levels of agreement is 75%. Initial inadequate level of agreement led to a discussion with the doctoral data analysts, in order to reach consensus between the coders. Re-testing followed, and results showed an adequate level of agreement between the data analysts; therefore, the codebook was finalised.

Chapter 4 Findings and Analysis

Introduction

This chapter presents data collected from the School of Life Sciences at the selected university where this research was conducted. The dataset consists of a mixture of qualitative and quantitative findings that examine the study's research questions from different perspectives. Lessons observed will not be presented individually as in-depth case studies, but rather, collectively, in order for the researcher to infer possible relationships between the way a practical lesson was designed and conducted, how the teaching of the lesson was influenced by undergraduates' and staff's beliefs, and the actual effectiveness of practical work tasks as measured *protinam* in the laboratory.

There are six sources of data in this study. The first section of the chapter considers results acquired from (1) a questionnaire adapted from Kerr (1963) which was distributed at the beginning of the academic year to 14 members of staff, asking them to put in ranking order their perceived aims of practical work for each academic year (Years 1, 2, 3) at the School of Life Sciences where they were teaching. Results were tabulated and the rank of each aim for each year was calculated based on the frequency of responses for each rank. Aims are presented in order of importance for each year. This will provide the background for the findings discussed next, as the perceived aims are logically and ideally the base on which members of staff structure and design lessons in the laboratory. In addition, it is expected that members of staff would use these aims when incorporating practical work objectives in the curriculum.

Findings from Section A will therefore be presented in an attempt to answer Research Question 1:

- What are the aims of practical work amongst a small representative sample of lecturers in the department of life sciences at the chosen university?

Next, (2) using Millar's (2009) observation instrument, notes concerning the features of lessons observed, along with teaching methodologies, will be presented in section B, from a total of 18 three- to four-hour Year 1 and Year 2 practical work classes throughout an entire academic year. It was evident that the way a practical work lesson was conducted and designed impacted undergraduates' learning; therefore, it is crucial to consider how information was delivered, in order to understand why practical work was effective or ineffective, and in what context.

Along with these practical work lesson characteristics, (3) descriptive statistics of informal undergraduates' on-the-spot assessment of laboratory skills and responses to experiment-related theoretical questions will be subsequently presented in section C. This allows an assessment of practical work's effectiveness, and if effective, the design features and teaching methodologies under which the lesson can have a positive impact – in this case, the development of undergraduates' skills and conceptual understanding.

Next, (4) semi-structured interviews with members of staff are presented, which were thematically analysed in order to understand their perceptions on the effectiveness of practical work, and their reflections on their teaching practices. Interviews with members of staff assisted in establishing an understanding of how directly linked factors, such as teaching methodologies and practical work lesson design, can affect the effectiveness of the practical work as a teaching practice. These sources of data, found in section D, were analysed and provide answers for Research Question 2:

- Are practical tasks effective in enabling undergraduates to do and/or learn what was intended? If yes, when?

Finally, the effectiveness of practical work was examined, as perceived by undergraduates as well as staff members. This allowed the methodological triangulation of results to increase reliability and validity, by cross-comparing claims on the effectiveness of practical work by members of staff, undergraduates, and from laboratory observations.

In sections E and F, results from (5) a questionnaire distributed to undergraduates, to measure meaningful learning by examining cognitive and affective aspects, were statistically analysed and compared to (6) undergraduates' on-the-spot interviews that assessed the effectiveness and affective value of practical work. This will consequently provide findings to answer Research Question 3:

- Does practical work contribute towards meaningful learning?
    - If so, to what extent does the affective value contribute to that meaningful learning?

Meaningful learning, as explained by Ausubel (1967), and in contrast to rote learning, occurs when information is understood through the integration of thinking, feeling and doing (Galloway, 2015), and can be used by building upon previous knowledge, to aid further understanding. Comparing undergraduates' expectations of practical work (pre-questionnaire) with their feedback on whether those expectations were fulfilled in the laboratory (post-questionnaire) will provide evidence on whether opportunities for meaningful learning arose in the laboratory, and thereby contributed to the effectiveness of practical work by developing conceptual understanding – given that this is a common expectation from practical work tasks.

Comparing undergraduates' expectations of practical work (pre-questionnaire on meaningful learning) with their feedback on whether those expectations were fulfilled in the laboratory (post-questionnaire on meaningful learning), along with the analysis of their interviews, will enhance the validity of the results. This aims to limit the reproduction of rhetoric, and therefore provide a true representation of the effectiveness of practical work in both affective and cognitive aspects.

It has been previously explained that the interpretation of data acquired from observations and interviews depends on the researcher and the lens through which reality is filtered and therefore analysed (Booth et al., 2001). For this reason, the data are analysed by applying the theoretical frameworks presented in Chapter 3, using the tools which have been successfully used before and were adjusted to meet the requirements of this study.

Data Analysis A - Members of Staff Questionnaire: The Aims of Practical work

Findings from Section A will be presented in an attempt to answer Research Question 1: What are the aims of practical work amongst a small representative sample of lecturers in the department of life sciences at the chosen university?

As previously mentioned, to reveal the basis upon which the chosen School of Life Sciences functions when incorporating practical activities in its curriculum, the aims of practical work as perceived by the lecturers/staff members when delivering laboratory classes should also be accounted for. This exploration provided this research with a framework for measuring the 'effectiveness' of practical work, examined in Research Question 2.

Additionally, identifying the aims of practical work in the department prior to observing laboratory lessons gave an opportunity to explore whether members of staff's perceptions were reflected in their practices, as effectiveness can only be measured based on the set learning objectives.

In answering "What are the aims of practical work amongst a small representative sample of lecturers in the department of life sciences at the chosen university?", an activity adopted from Kerr (1963), in which 10 aims of practical work (discussed in Chapter 3, Figure 16) were presented to be ranked in order of importance, was administered to members of staff (one list of 10 aims for each year) for each year of the undergraduates' three-year degree programme in life sciences.

Data acquired from 14 members of staff are presented in the following graph, showing the average ranking for each aim by Year (Year 1: orange, Year 2: yellow, Year 3: green). Amongst the data presented, each year displays the aims of practical work in ranked order, with 1 being regarded as the most important and 10 the least important.

Figure 18

Aims of Practical Work – A comparison between the years

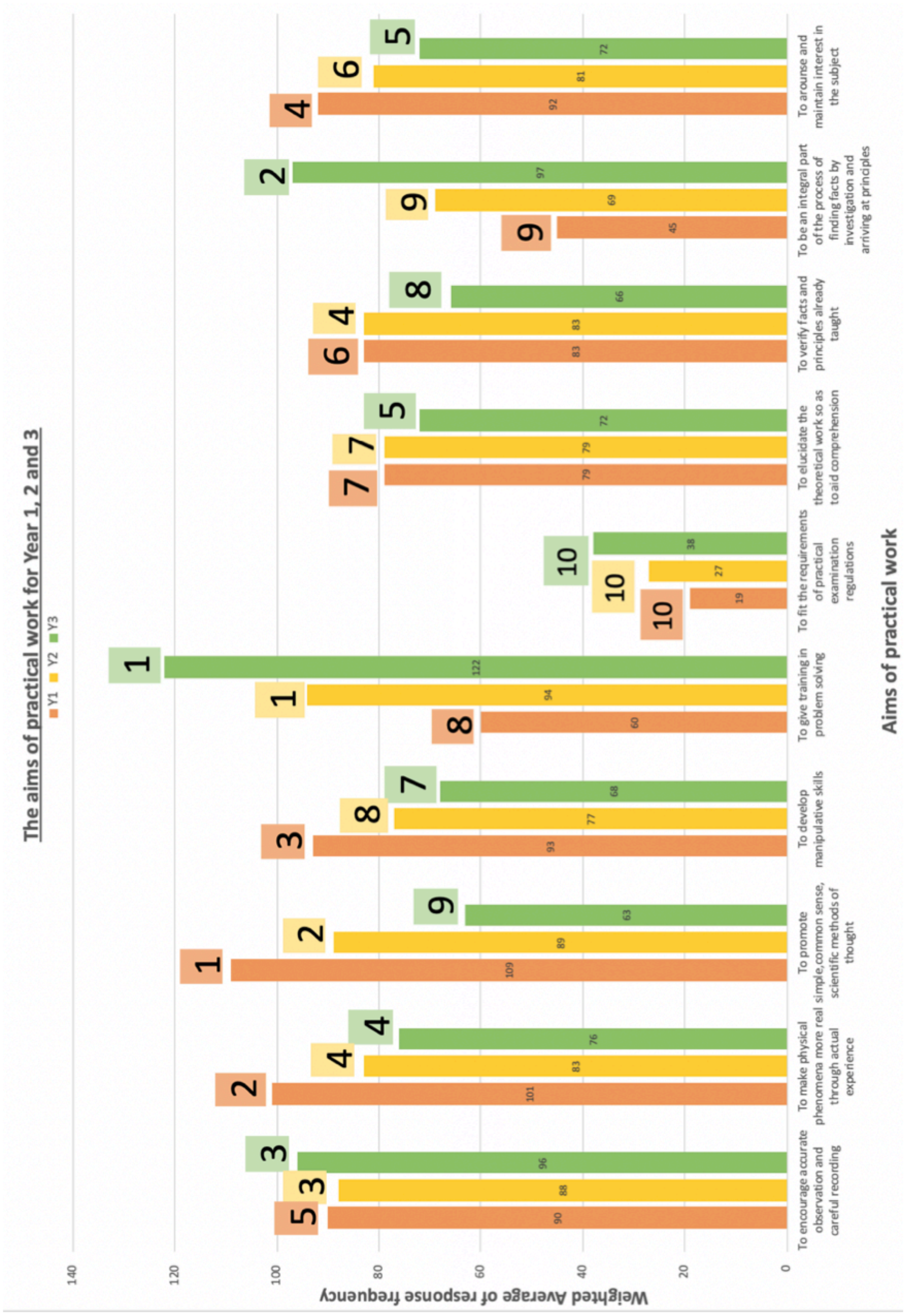


Figure 18a

Aims of Practical Work – Categorised into themes

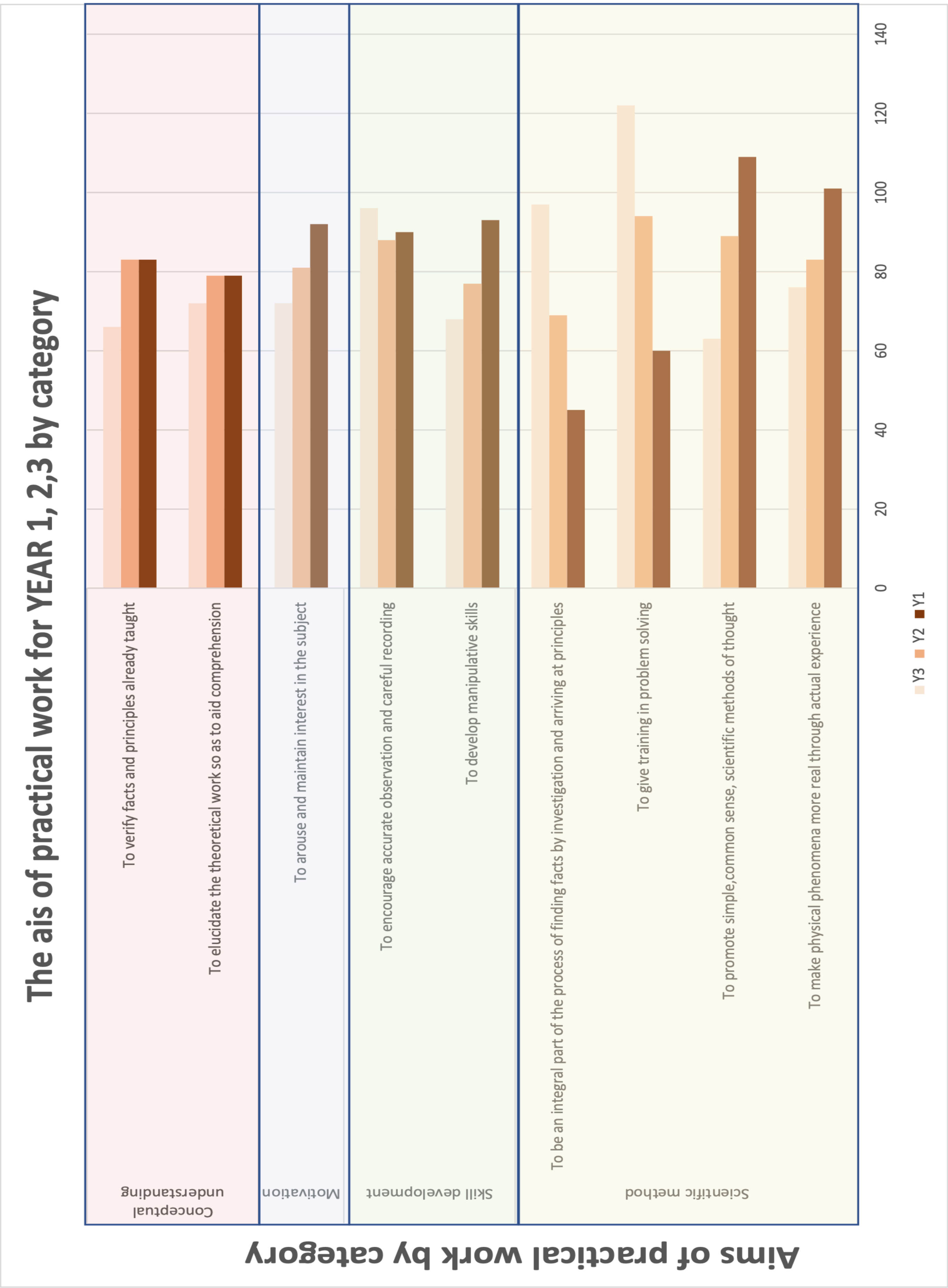
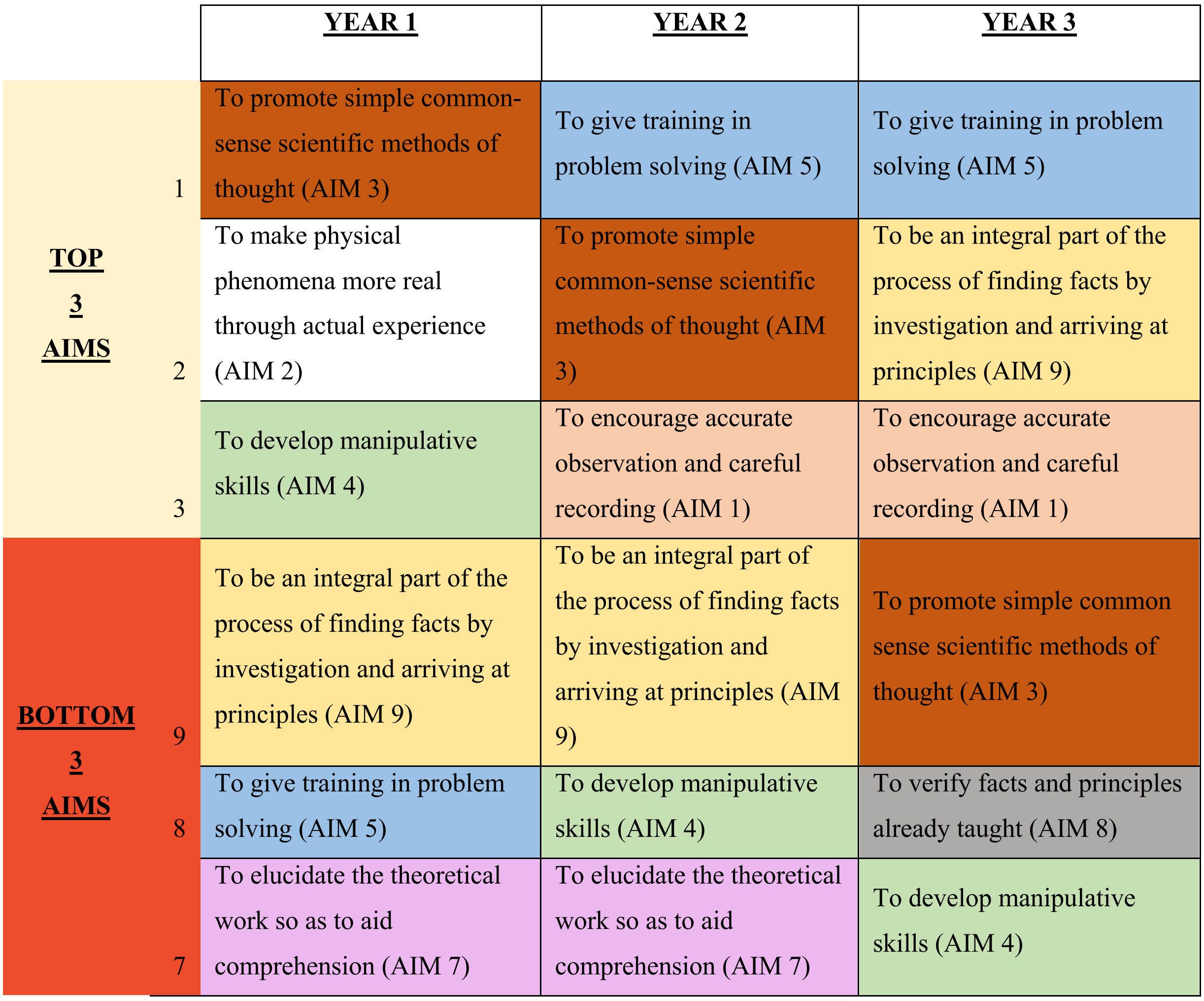


Figure 19

Trends by colour: Aims of Practical Work – a comparison between the years



		YEAR 1	**YEAR 2**	**YEAR 3**
TOP 3 AIMS	1	To promote simple common-sense scientific methods of thought (AIM 3)	To give training in problem solving (AIM 5)	To give training in problem solving (AIM 5)
	2	To make physical phenomena more real through actual experience (AIM 2)	To promote simple common-sense scientific methods of thought (AIM 3)	To be an integral part of the process of finding facts by investigation and arriving at principles (AIM 9)
	3	To develop manipulative skills (AIM 4)	To encourage accurate observation and careful recording (AIM 1)	To encourage accurate observation and careful recording (AIM 1)
BOTTOM 3 AIMS	9	To be an integral part of the process of finding facts by investigation and arriving at principles (AIM 9)	To be an integral part of the process of finding facts by investigation and arriving at principles (AIM 9)	To promote simple common sense scientific methods of thought (AIM 3)
	8	To give training in problem solving (AIM 5)	To develop manipulative skills (AIM 4)	To verify facts and principles already taught (AIM 8)
	7	To elucidate the theoretical work so as to aid comprehension (AIM 7)	To elucidate the theoretical work so as to aid comprehension (AIM 7)	To develop manipulative skills (AIM 4)

As seen in Figure 18, an initial exploration showed that 'giving training in problem solving' (Aim 5) was ranked as the most important aim for Years 2 and 3 and of less importance for Year 1. In Year 1, 'promoting simple, common-sense scientific methods of thought' (Aim 3) was ranked as the most important, and second most important in Year 2. In contrast with the ranked order of the previously mentioned aim for Years 1 and 2, members of staff ranked it as one of the least important for Year 3. Moreover, even though 'finding facts by investigation and arriving at principles' (Aim 9) was ranked amongst the top aims (second for Year 3), it was again seen at the bottom rank for Years 1 and 2.

In Figure 18a aims of similar intentions were clustered together and a cluster ranking is presented. Kerr's aims were extended by several other authors including Shulman and Tamir (1973) who suggested that the aims fall into categories; acquisition of skills, development of conceptual understanding, development of cognitive abilities, exposure to the nature of science/the scientific method and motivation. In the graph there are four main themes represented, scientific method, skill development, motivation and conceptual understanding. For each theme, Kerr's aims are ranked in terms of importance. In each column of the graph representing a different year, bars representing the importance rating given by members of staff for the specific aim are presented. Overall, the highest rated aim for Year 1 was, again, to promote simple, common sense, scientific methods of thought under the theme of 'exposure to the nature of science/the scientific method' and for the second and third years ' To give training in problem solving'. This shows that the exposure to the nature of science/scientific method was prioritised in the laboratory. Moreover, in all three years aims falling under the category of skill development were amongst the top three highly ranked aims (To develop manipulative skills; To encourage accurate observation and careful recording). Lastly, the only aim falling under the category of conceptual understanding was ranked second highest for third year undergraduates. Generally, hands-on experiences and experiments were part of the learning process with emphasis put on the use of the scientific methods and skill development.

In a general context, amongst the top three most important aims for Year 3, 'To give training in problem solving' (Aim 5) and 'To be an integral part of the process of finding facts by investigation and arriving at principles' (Aim 9) are seen as the least important two aims for Year 1 (Figure 19). The same pattern is identified for Year 1, as its three most important aims, including 'To promote simple common-sense scientific methods of thought' (Aim 3) and 'To develop manipulative skills' (Aim 4), are amongst the least important aims for Year 3.

Lastly, there is an agreement amongst all three years on the unimportance of doing practical work to fit the requirements of practical examination regulations (Aim 6), which was ranked as the least important aim of practical work.

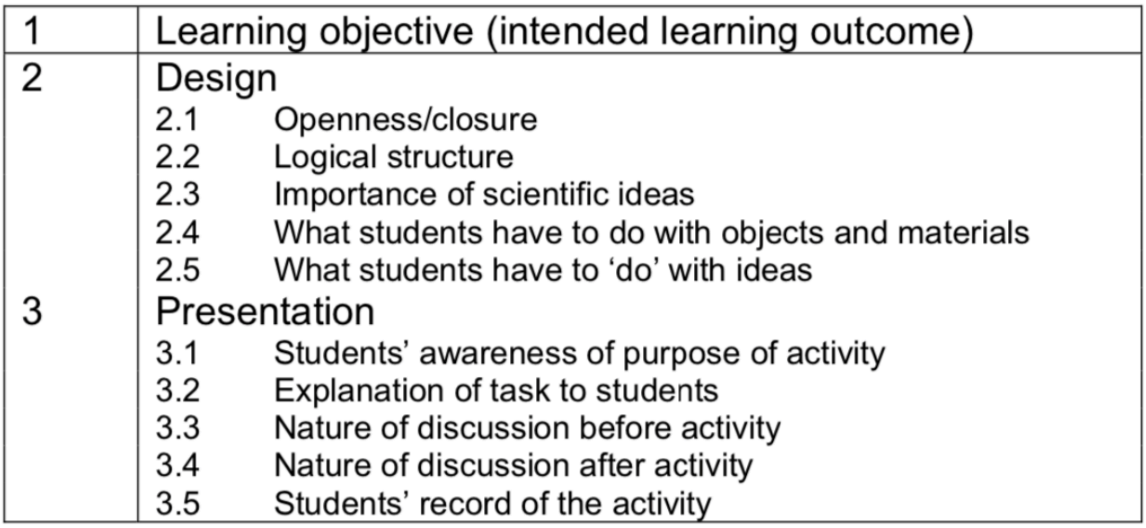
To conclude, based on the results acquired, the promotion of simple scientific methods of thought was prioritised in Year 1 (ranked the highest), whereas in Year 3 it was ranked the lowest. Problem solving, on the other hand, was prioritised in Year 3 (ranked the highest) and Year 2, whereas it was ranked amongst the lowest for Year 1. Lastly, 'finding facts by investigation and arriving at principles' was prioritised in Years 2 and 3, unlike the similar ranking shown in Figure 18, and, again, was regarded as one of the least important aims for first-year undergraduates.

Data Analysis B – Practical Work Lesson Observations: Design of Practical Work Lessons

Findings from Section B and C will be presented in an attempt to answer Research Question 2:[Based on the features of the practical work lesson observed] Are practical tasks effective in enabling undergraduates to do and/or learn what was intended? If yes, when?

A major part of this research was time spent in the laboratory, observing three- to four-hour practical work lessons of undergraduates studying a three-year degree at the School of Life Sciences (Chapter 3, Table 6). Due to the variation in teaching practices and types of inquiry observed, in order to make the observation process as standardised as possible while attending 18 practical work lessons, an adapted tool created by Millar (2009) was used to track details regarding the design of the practical activity, as well as the way it was presented to the students (Table 9). Exploring the structure of the practical work lessons allowed the researcher to observe whether the aims of practical work according to members of staff (examined in Research Question 1) were reflected in their actual practice while designing and delivering practical work lessons. Additionally, the design of practical work lessons gave a clear perspective on lesson characteristics, which can directly contribute to the effectiveness of practical work, when observed.

Table 9
Components of laboratory observation instrument (adapted from Millar, 2009, p. 6)



1	Learning objective (intended learning outcome)	
2	Design	
	2.1	Openness/closure
	2.2	Logical structure
	2.3	Importance of scientific ideas
	2.4	What students have to do with objects and materials
	2.5	What students have to 'do' with ideas
3	Presentation	
	3.1	Students' awareness of purpose of activity
	3.2	Explanation of task to students
	3.3	Nature of discussion before activity
	3.4	Nature of discussion after activity
	3.5	Students' record of the activity

Initially, what differentiated the observed practical activities from each other was their learning goals, which were split into three main categories: development of knowledge, development of skills, and developing understanding of the scientific approach to enquiry. On certain occasions, lessons included learning objectives from two or more categories; in that case, more categories were selected for the instrument. As observed in Table 10, undergraduates were only expected to directly develop their knowledge and understanding of the natural world for two Year 1 and three Year 2 practical work classes. However, in almost all of the practical work lessons observed for Year 1, undergraduates were expected to learn how to use a piece of equipment or follow a standard practical procedure they were either familiar or unfamiliar with. The same applied for Year 2 undergraduates, although the number of times they had to use a piece of equipment or follow a procedure they had not previously met was lower than for Year 1.

Table 10

Learning Goals: Observation instrument – number of times each objective was part of the practical work class observed (adapted from Millar, 2009, p. 6)

Objectives	Y1	Y2
By doing this activity undergraduates should develop their knowledge and understanding of the natural world. Undergraduates have a better understanding of a scientific idea or concept or explanation or model or theory.	2	3
By doing this activity undergraduates should learn how to use a piece of laboratory equipment or follow a standard practical procedure they have previously met.	8	7
Undergraduates can use a piece of equipment or follow a practical procedure that they have not previously met.	7	4
By doing this activity undergraduates should develop their understanding of the scientific approach to enquiry.	2	5

Specific aspects of scientific enquiry	**Y1**	**Y2**
Identify a research question	0	1
Plan a strategy for collecting data to answer a research question	1	4
Choose the right equipment for an investigation	0	2
Present data clearly	0	2
Analyse data to present patterns	0	3
Draw conclusions based on evidence	2	5
Assess how confident you can be that a conclusion is correct	1	5

Table 11

Design – observation instrument (adapted from Millar, 2009, p. 6)

Design

Openness / Closure (tick 1 box)	Y1	Y2
Questions given, detailed instructions on procedure	9	9
Questions given, outline guidance on procedure, some choices left to undergraduates	0	0
Questions given, but undergraduates choose how to proceed	0	0
Undergraduates decide the question and how to proceed	0	0

Table 12

Logical structure – observation instrument (adapted from Millar, 2009, p. 6)

Logical Structure of the activity (tick 1 box)	Y1	Y2
Collect data on a situation, then think about how it might be summarised or explained	5	6
Use your current ideas to generate a question or prediction; collect data to explore or test	0	3
Other	4 (Develop a skill)	0

With regard to the learning outcomes of developing a scientific approach to enquiry, Year 1 undergraduates were only involved twice in such practical activities, where they were either asked to draw conclusions based on evidence in the laboratory during their practical activity, to self-assess their results, or to plan a strategy to collect their data in order to answer a research question. In contrast to Year 1, Year 2 undergraduates had more opportunities to engage with practical activities aiming to develop their scientific approach to enquiry, as they were engaged with tasks such as identifying a research question, planning strategies to answer their research questions, choosing appropriate equipment, presenting and analysing data accurately, and drawing conclusions based on evidence, as well as self-assessing their findings.

The design of the practical activities is an important factor in terms of communicating the research question to be investigated, the methodologies that will be used, how to follow the protocol, and how to interpret the results (Millar, 2009). As seen in Table 11, in all 18 practical activities observed in both Year 1 and Year 2, the lecturer determined the question given and the instructions on how to follow the protocol and interpret the results. Members of staff gave undergraduates detailed verbal instructions, and a guidebook explaining the experiment step by step and the results they were expected to see, linked with relevant theoretical background.

An important aspect of practical work is its logical structure and the way it incorporates thinking and doing within the activity (Millar, 2009) (Table 12). Apart from four Year 1 practical activities which were mainly focused on developing a skill, five Year 1 and six Year 2 practical activities expected undergraduates to collect data, by making observations and taking measurements on a situation, in order to see how results can then be explained. On the other hand, only three Year 2 practical activities expected undergraduates to think about the experiment, use ideas to generate a research question and possibly a hypothesis, before collecting data to test whether their predictions were correct; i.e., by integrating thinking and doing.

Table 13

Importance of scientific ideas to carry out the activity well (1: unimportant, 2: not very, 3: fairly, 4: essential) – observation instrument (adapted from Millar, 2009, p. 6)

Importance of scientific ideas	**Y1**	**Y2**
Average (9 classes/year)	1.66	2.5

Three Year 2 practical activities, as seen in Table 12, required undergraduates to have some scientific knowledge about the task, to form hypotheses and make predictions on possible results, before starting the experiment. Table 13 shows the importance of having scientific understanding in order to carry out an activity well. As most practical activities for Year 1 focused on developing skills (Table 10), the average learning demand was 1.66, translating as unimportant to not very important. This means that activities could be performed without undergraduates needing relevant scientific knowledge. Year 2 focused on developing skills and engaging with the scientific way of thinking (Table 10). The learning demand increased but still remained relatively low, with an average learning demand of 2.5, meaning not very important to fairly important. The difference between Year 1 and Year 2 is expected, as there were classes in Year 2 that required undergraduates to use their ideas (Table 12) before starting their experiment. However, the fact that Year 2 undergraduates engaged with the scientific approach to enquiry should logically have increased the learning demand, which in this case remains relatively low.

Table 14
What students have to do with objects and materials – observation instrument (adapted from Millar, 2009, p. 6)

What students have to do with objects and materials (tick all that apply)	Y1	Y2
Use an observing or measuring instrument	7	5
Follow a standard practical procedure	8	4
Present or display an object or material	3	2
Make an object	0	2
Make a sample of a material or substance	0	1
Make an event happen (produce a phenomenon)	1	2
Observe an aspect or property of an object, material or event	2	4
Measure a quantity	1	4

Table 15

What students have to 'do' with ideas – observation instrument (adapted from Millar, 2009, p. 6)

What students have to 'do' with ideas	**Y1**	**Y2**
Report observations using scientific terminology	8	8
Identify a similarity or difference (between objects, materials or events)	0	1
Explore the effect on an outcome of a specific change	0	2
Explore how an outcome variable changes with time	0	1
Explore how an outcome variable changes when the value of a continuous independent variable changes	0	0
Explore how an outcome variable changes when each of two or more independent variables change	0	0
Design a measurement or observation procedure	0	0
Obtain a value of a derived quantity	4	0
Make and/or test a prediction	2	2
Decide if a given explanation applies to the particular situation observed	0	3
Decide which of two or more given explanations best fits the data	0	0
Suggest a possible explanation for data	2	7

Table 14 shows what undergraduates were required to do with objects and materials in a practical activity. As observed, multiple categories could be selected for each practical activity. For instance, Year 1 undergraduates, in most of the practical activities undertaken, had to follow a standard practical procedure and use observing or measuring instruments (i.e. measure a quantity to prepare a solution). For Year 2 they had to observe aspects of an object or event and measure quantities (i.e., count bacterial colonies and measure percentage of infection).

Apart from working with objects, practical activities required undergraduates to work with ideas (Table 15). The most observed objective in both Year 1 and Year 2 was to report observations using scientific terminology in their workbooks or reports after they finished the practical activity. In one practical activity in Year 2, undergraduates had to identify similarities or differences between objects (i.e. compare bacterial cultures in two broths of different dilution), so they had to make inferences from their findings. In categories 3–6, undergraduates were expected to report a relationship between variables. Those categories were seen in Year 2 practical work lessons, and usually undergraduates had to create graphs to show the difference over time or the effect of an outcome on a change (i.e. observing crickets' feeding behaviour when exposed to three different diets after starvation). Categories 9–12 required undergraduates to think and engage with ideas, as they either needed to test a prediction, decide if their explanation applied to the situation observed, or suggest a possible explanation for data; this was frequently seen in Year 2 practical work lessons.

Important aspects of a practical activity and its level of effectiveness are the way its purpose is communicated and explained to undergraduates, whether there is discussion about it for exchanging ideas, and how findings are recorded. In order for undergraduates to carry out an activity proficiently, they need to understand why they are doing it. In Year 1, as it can be seen in Table 16, the activity was either proposed by an academic, with or without links to previous work; or class discussion was used to help undergraduates see how the activity related to theory and the research questions. In Year 2, seven out of nine observed practical work lessons involved class discussion with the undergraduates. Most members of staff gave an introductory talk to refresh undergraduates' memory on the topic of the practical activity, and to either introduce new information or reinforce what had already been taught.

Table 16

How is the purpose of the experiment communicated to undergraduates? Observation instrument (adapted from Millar, 2009, p. 6)

Presentation

How is the purpose of the experiment communicated to undergraduates?	Y1	Y2
Activity is proposed by the academic, no explicit links made to previous work	3	1
Purpose of activity is explained by the academic and explicitly linked to preceding work	3	1
Academic uses class discussion to help undergraduates see how the activity can help answer a question of interest	3	7
Purpose of activity readily apparent to the undergraduates, clearly follows from previous work	0	0
Activity is proposed and specified by the undergraduates following discussion	0	0

Along with the purpose of the experiment, the activity needs to be explained to undergraduates so that they understand what they need to do (Table 17). If the intentions of members of staff are not communicated clearly, then undergraduates would be unable to do and learn what is required, as they would fail to understand the instructions they need to follow. In most cases for both Year 1 and Year 2, the activity was explained both orally and on a worksheet. In total, five times for Year 1 and five times for Year 2, written instructions and notes were presented on a monitor that was on throughout the practical work lesson. In four observed classes of Year 1, and in one of Year 2, all or part of the procedure was first demonstrated by a member of staff, so that undergraduates could first observe and then do as instructed.

Table 17

How is the activity explained to undergraduates? Observation instrument (adapted from Millar, 2009, p. 6)

How is the activity explained to undergraduates? (tick all that apply)	**Y1**	**Y2**
Orally by the academic	9	7
Written instructions on a monitor/projector/screen	5	5
Worksheet	8	6
All or part of the procedure demonstrated by the academic beforehand	4	1

In order to understand how to link ideas with the practical activity or how to interpret findings, discussion is important in helping students develop conceptual understanding (Millar, 2009) Before the practical activity, as shown in Table 18, the researcher more often observed discussion that involved talking about the equipment and the procedures to be used, going through the protocol, as well as introducing ideas and theories that could be linked to the activity. In addition, aspects of scientific enquiry were introduced so that undergraduates could relate them to the activity. Only three times in both Year 1 and Year 2 were undergraduates seen to start working on their experiment without having any discussion with peers and members of staff.

Table 18

Whole class discussion before the practical activity begins? Observation instrument (adapted from Millar, 2009, p. 6)

Whole class discussion before the practical activity begins? (tick all that apply)	**Y1**	**Y2**
None	2	1
About equipment and procedures to be used	6	4
About ideas, concepts, theories and models that are relevant to the activity	4	5
About aspects of scientific enquiry that relate to the activity	4	1

Table 19

Whole class discussion following the practical activity – observation instrument (adapted from Millar, 2009, p. 6)

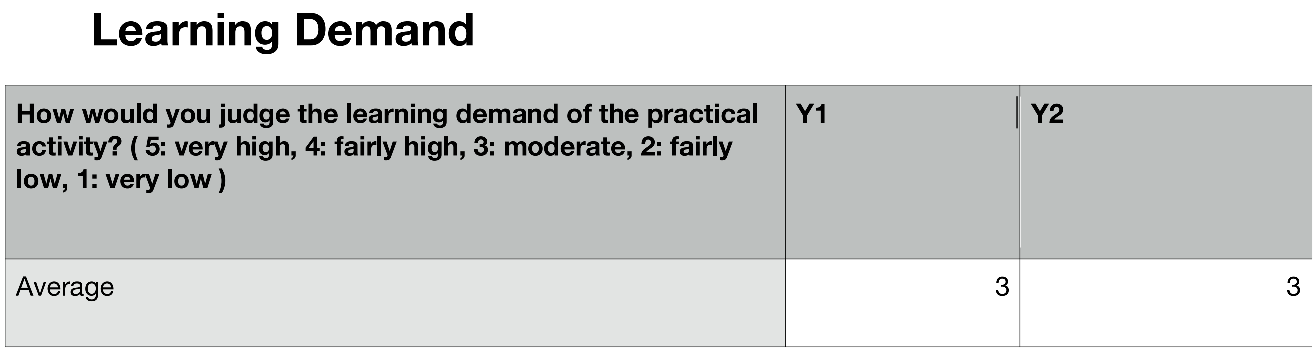
Whole class discussion following the practical activity? (tick all that apply)	**Y1**	**Y2**
None	2	0
About confirming "what we have seen"	7	6
Centred on a demonstration in which the teacher repeats the practical activity	0	0
About how to explain observations, and to develop conceptual ideas that relate to the task	1	7
About aspects of investigation design, quality of data, confidence in conclusions, etc.	0	2

As observed in Table 19, for Year 1, two times out of nine there was no discussion after the practical activity. For the rest of the classes observed, discussion involved confirming results and what undergraduates had seen, and how to develop a conceptual understanding by linking the ideas to the task. The opposite was the case for Year 2: in most of the practical classes observed, members of staff confirmed what undergraduates saw in their experiment, and explained observations and how they could be linked to theories. In addition, in Year 2, members of staff also discussed the quality of data and confidence of undergraduates in their conclusions and findings, as they were usually expected to proceed in writing an assessed report.

Table 20
Students' record of the activity – observation instrument (adapted from Millar, 2009, p. 6)

Undergraduates' record of the activity (tick 1 box)	**Y1**	**Y2**
None	0	0
Notes, as the undergraduate wishes	3	1
A completed worksheet	5	4
Written report with a given structure and format	1	4
Written report in a format chosen by the undergraduate	0	0

Table 21
How would you judge the learning demand of the practical activity? – observation instrument (adapted from Millar, 2009, p. 6)



Learning Demand

How would you judge the learning demand of the practical activity? (5: very high, 4: fairly high, 3: moderate, 2: fairly low, 1: very low)	Y1	Y2
Average	3	3

A final aspect of the classes was the presentation of undergraduates' work. In Year 1, as observed in Table 20, five out of nine times, undergraduates were expected to complete a worksheet. For Year 2, eight out of nine times undergraduates were expected either to complete a worksheet, or write a report with a given structure and format predetermined by members of staff. As for assessment (Table 22), Year 1 undergraduates were expected either to self-evaluate their findings, complete a worksheet, a multiple-choice question test, or write a report. Moreover, the most frequent way of assessing Year 2 undergraduates' work was through a report in which they recorded ideas and demonstrated understanding of the findings and theories linked to them. This can be combined with data presented in Table 12 where in most cases both Year 1 and Year 2 undergraduates collected data on a situation, then thought about how it might be summarised or explained after the practical activity.

Generally, the learning demand for both Year 1 and Year 2 practical activities was moderate, allowing undergraduates to perform experiments from start to finish; even if they lacked the necessary theoretical background to explain, during the experiment, why they were doing these tasks and how findings could be linked to ideas and theories.

Table 22
Assesment

Assessment (tick 1 box)	**Y1**	**Y2**
None	2	0
Self-evaluation	2	0
Report	1	7
Multiple-choice questions (MCQ)	2	2
Worksheet	2	0

Data Analysis C – Practical Work Effectiveness: Informal Assessment of Undergraduates' Conceptual Understanding and Skill Development

Findings from Section C and B will be presented in an attempt to answer Research Question 2:[Based on undergraduates' performance] Are practical tasks effective in enabling undergraduates to do and/or learn what was intended? If yes, when?

In this research, the effectiveness of practical work was informally assessed on two levels of effectiveness, following a theoretical model developed Millar (2009), which was introduced and discussed in Chapter 3. This framework helped in evaluating two levels of effectiveness – 'What undergraduates do' and 'What undergraduates learn' – which are further divided into two domains introduced by Tiberghien (2000): the domain of observables and the domain of ideas.

Firstly, undergraduates were observed in order to examine whether what they did with objects and materials was what the members of staff had intended when they designed the practical activities (Effectiveness Level 1: Domain of Observables). Also, whilst doing with observables and materials, it was observed whether undergraduates thought about their actions using ideas that members of staff wanted them to use (Effectiveness Level 1: Domain of ideas). Secondly, undergraduates were informally assessed by subject-related on-the-spot interviews about what they had learned, and whether this was what members of staff had intended them to learn in order to understand ideas and theories (Effectiveness Level 2: Domain of Ideas). In addition, undergraduates were examined regarding whether they could later recall what they did with objects and materials, and whether they knew and could explain what they had observed or what their data meant (Effectiveness Level 2: Domain of Observables).

Descriptive statistics of undergraduates’ responses to theoretical questions underlying their experiment are demonstrated, in order to assess the effectiveness of practical work in terms of conceptual understanding of theories and the acquisition of laboratory taught skills.

Table 23

Analytical framework for the effectiveness of practical work, adapting the domains of knowledge by Tiberghien (2000) and levels of effectiveness by Abrahams and Millar (2008). Modified table by Abrahams and Millar (2008, p. 5)

Assessment of effectiveness for 18 practical work activities.

Adapted from 'The practical activity analysis inventory', Millar (2009, p. 21)

Learning outcomes	**Domain of observables**	**Domain of ideas**
Level 1 (what undergraduates do)	"the [undergraduates] do with the objects and materials provided what the [lecturer] intended them to do, and generate the kind of data the [lecturer intended]" (Abrahams & Millar, 2008, p. 5)	"whilst carrying out the task, the [undergraduates] think about their actions and observations using the ideas that the [lecturer] intended them to use" (Abrahams & Millar, 2008, p. 5)
Level 2 (what undergraduates learn)	"the [undergraduates] can later recall things they did with objects or materials, or observed when carrying out the task, and key features of the data they collected" (Abrahams & Millar, 2008, p. 5)	"the [undergraduates] can later show understanding of the ideas the task was designed to help them learn" (Abrahams & Millar, 2008, p. 5)

Effectiveness at Level 1

Domains of Observables and Ideas

Table 23 presents the theoretical 2 x 2 matrix discussed in Chapter 3. Initially, for effectiveness at Level 1 and in the domain of observables, Table 23 shows that in most of the practical work lessons observed in Year 1 (8/9) and Year 2 (4/5), undergraduates knew how to use the equipment involved, along with setting up the apparatus and handling everything correctly, following health and safety regulations (Year 1: 9/9; Year 2: 7/9); therefore, they were doing with objects and materials what the members of staff intended them to do. Moreover, with the help of the demonstrators, the introductory talk by members of staff, and their guidebook, undergraduates could give an explanation of why they were applying those techniques, and what sort of observations were expected based on the ideas and theories given to them.

Samples of interview exchanges further attest to this:

> *Researcher: You seem to have prepared your agar fine there.*
>
> *Student 1: Oh I am [getting] more comfortable with preparing a gel. At least it does not spill in the microwave now.*
>
> *Researcher: Do you know how run a PCR? [Polymerase Chain Reaction molecular test]*
>
> *Student 2: On my own? Vaguely. Only when I follow the protocol.*
>
> *Student 3: When you do it one to two times you need guidance. Just to double-check. Then you become very comfortable in doing it on your own. Like now.*
>
> *Researcher: Which pipette would you use for 70 ml? [Most of the group answered correctly]*

> *Group of students: [Showing a 100µl pipette] It is more accurate when you use a pipette that can dispense a volume of liquid similar to the one you want to have.*

Undoubtedly, some undergraduates had difficulties with the equipment, but could eventually use everything correctly with some assistance:

> *Researcher: Did you find it easy to prepare a PCR?*
>
> *Student 5: Well, we did not know what we were doing until a technician helped us. We did it wrong, hopefully it will go okay now.*

A: Effectiveness at level (1)

Key question: Did students do what they were intended to do, and see what they were intended to see?

Table 24

Effectiveness of practical work at level 1. Summary of practical work lessons (18 in total) that meet each criteria. Modified table by Millar (2009, p. 24)

		Mainly Yes	**Mainly No**	**Not Applicable**
1	**Did students know how to use the equipment involved?**	Y1: 8 Y2: 4	Y2:1	Y1: 1 Y2: 4
2	**Were students able to set up the apparatus, and handle materials involved correctly and safely?**	Y1: 9 Y2: 7	0	Y2: 2
3	**Were students able to use the apparatus with sufficient precision to make the necessary observations or measurements?**	Y1: 8 Y2: 4	Y2: 1	Y2: 4
4	**Were students able to carry out any routine procedures involved?**	Y1: 9 Y2: 6	0	Y2: 3
5	**Were students able to follow any oral or written instructions given?**	Y1: 9 Y2: 9	0	0
6	**Did students observe the outcome(s) or effect(s) you wanted them to see?**	Y1: 2 Y2: 3	Y1: 5 Y2: 6	Y1: 2 Y2: 0
7	**Could students explain the purpose of the activity if asked? (what they were doing it for)**	Y1: 8 Y1: 9	Y1: 1 Y2: 0	0
8	**Did students talk about the activity using the scientific terms and ideas you would have wished them to use?**	Y1: 3 Y2: 3	Y1: 6 Y2: 6	0

Moreover, in most of the practical work classes observed, the majority of undergraduates could use the equipment in a correct way that allowed them to be precise and make necessary observations (Year 1: 8/9; Year 2: 4/5). All routine procedures could be carried out smoothly and correctly (Year 1: 9/9; Year 2: 6/6), accurately following oral and written instructions provided to them (Year 1: 9/9: Year 2: 9/9). Clear communication of main objectives by members of staff (Table 18) enabled the overwhelming majority of undergraduates in the observed practical work lessons to explain the purpose of the activity asked (Year 1: 8/9; Year 2: 9/9).

However, few undergraduates were using scientific language to clearly communicate the theories and ideas underlying their actions (Year 1: 2/7; Year 2: 3/9), and could only observe the outcomes members of staff wanted them to see when they received guidance (Year 1: 3/9; Year 2: 3/9). This reflects the domain of ideas at Level 1 effectiveness, where undergraduates need to think about their observations not only as direct observations, but also in terms of underlying ideas. This is demonstrated in the interview samples from different practical activities presented below:

<u>Preparing slides with canine faecal samples</u>

Researcher: Do you know what you are looking at down the microscope? (canine faecal sample)

Student 6: It looks disgusting, but no.

Researcher: What does the egg of the parasite look like?

Student 6: Well, the egg is chubby but maybe what I am looking at is a bubble? No idea.

<u>Preparing slides with cheek cells for a Papanicolaou stain</u>

Researcher: Do you actually know what the green pigment in this slide is?

Group of students: We will figure it out between us. It means that it absorbed more green pigment than purple.

Researcher: The green stains the cytoplasm of the cells.

Group of students: Oh! That's why there are so many. Everything looks so colourful. And there are nice shapes as well. Are those cells? What is the dot in the middle?

Researcher: That is the nucleus.

Lecturer: They do not need to know for now. They will learn about it in the lecture later.

Undergraduates preparing their gels for PCR

Researcher: Do you know why we need to load a ladder in the PCR?

Group of students: I do not know what a ladder is.

Researcher: That tells you the size of your DNA band. [The DNA ladder has DNA fragments of different molecular weights which can be seen as DNA bands in the gel]

Group of students: Oh, we forgot.

Researcher: Do you know why we have cold and hot phases in PCR?

Group of students: It's in the protocol… Let's see. Not sure. We will ask a demonstrator.

Using immunofluorescent staining

Group of students: We finished using this 'stuff' [rinsing with phosphate-buffered saline solution]

Lecturer: Did you keep your slides in the dark?

Student: Erm, no.

Researcher: Your slides are destroyed by light as the samples are photosensitive, the fluorescent dye is affected. Your samples were photobleached.

Lecturer: Let's use someone else's slide. Those are your cells.

Students: Oh cool! They are neon coloured. What are we seeing again, sir?

Staining tissue in histology class using haematoxylin and eosin

Researcher: Can you identify the organ that you are observing under the microscope?

Lecturer: What are those curved bottle-like structures at the top?

[Undergraduates could not identify the tissue because they had to remember organ characteristics from their anatomy lectures.]

Group of students: [Silent]

Lecturer: Those curved structures are indentations and they are the gastric pits. They line the epithelium.

Researcher: Does that make sense now?

Group of students: Yes! Now that we saw it, we will remember. It was difficult to tell because we did not understand what we were looking at, but now that you showed us it makes sense.

Anatomy of plants

Researcher: Can you show me the phloem and xylem?

Student: I have no idea, this slide has a lot of colours.

Researcher: If you remember the structurer of a stem, where would you find the xylem?

Student: I do not know, what is that structure called … skin?

Researcher: You mean epidermis?

Student: Yes. That!

In this respect, the interview samples above appear to support the findings, as undergraduates could not observe the results the lecturers intended them to observe, unless they received support from members of staff.

Effectiveness at Level 2

Domains of Observables and Ideas

Having presented results regarding what undergraduates did with observables and ideas, this section examines effectiveness at Level 2, considering what undergraduates learned in the practical work lessons. Using Abrahams and Millar's model (2009), in the domain of observables, Table 23 shows whether undergraduates could recall what they did with objects and what they observed, along with main findings. In addition, in the domain of ideas, evidence is provided for whether undergraduates could understand the ideas underlying the practical activity that the lecturer wanted them to learn. Undergraduate percentages are assigned to three categories (most, some, only a few), with 'most' indicating the majority (51–100%), 'some' meaning 26–50%, and 'only a few' indicating 0–25% of the class.

Table 25

Effectiveness of practical work at Level 2. Summary of practical work lessons (18 in total) that meet each criteria. Modified table by Millar (2009, p. 24)

B: Effectiveness at level (2)

Key question: Did students learn?

Class ID Year 1	Remember	Understand	Student number
CellBiology	42%	47%	95
Biochemistry	37%	44%	86
Biochemistry	Skill development	Skill development	86
Microbiology	37%	37%	95
Microbiology	37%	39%	95
Histopathology	18%	20%	100
Plant Biology	62%	77%	52
Plant Biology	73%	81%	52
Biochemistry	Skill development	Skill development	86

Only a few : 0–25% **Some: 26–50%** **Most: 51–100%**

Class ID Year 2	Remember	Understand	Student number
Immunopathology	35%	38%	100
Animal Nutrition	75%	88%	40
Zoology	50%	50%	40
Pharmacology	27%	31%	48
Biology of Diseases	33%	38%	60
Molecular Biology	9%	9%	136
Biochemistry	18%	12%	83
Immunopathology	43%	47%	100
Biochemistry	17%	18%	83

Only a few : 0-–5% **Some: 26–50%** **Most: 51–100%**

Table 25 shows that in six practical activities, undergraduates demonstrated to varying degrees (percentages range from 37% to 73%) that they could recall what they did with objects, and the main features of what they had observed in previous lessons, when asked in follow-up practical work lessons. Similarly, this was also observed in six Year 2 practical work lessons, with percentages ranging from 27% to 75%.

Some examples of conversations with undergraduates follow, showing that a number of them could recall what they did and remembered information about observables, so as to apply it to future classes.

> *Researcher: You seem to remember how to use your pipettes and scales! Well done.*
>
> *Group of students 1: We remember! Repetition helps us master the skill. After all, we practised again in our class two weeks ago.*
>
> *Researcher: Are you confident with your dilutions? You know that this is a crucial step for your experiment?*
>
> *Group of students 2: Yes, we know how to do it! We learned in our first year. You can see the benefits in the long run. You cannot see instant results, but we just start doing things automatically and it seems that we remember. By the end of the year we will be able to do more things confidently.*
>
> *Student 1: I also remember things from my foundation year. Repetition indeed helps you build a strong skillset.*
>
> *[Most of the undergraduates did their calculations correctly]*

With regard to undergraduates developing their conceptual understanding of ideas as members of staff had intended, while conducting their experiments for Year 1, out of nine laboratory sessions per year, undergraduates in six practical work lessons (37–81%) demonstrated that they understood, again to varying degrees, the ideas that members of staff had intended them to understand when designing the activity. Similarly with Year 2, undergraduates in six practical work lessons (31–88%) showed confidence in showing an understanding of some ideas.

Table 26 presents details concerning the structure of the observed practical work lessons, in an attempt to explore whether there is any pattern that contributes to practical work's effectiveness in terms of understanding and remembering ideas. Practical work lessons cannot be directly compared to each other, but it is possible to examine characteristics of their structure that were successful, and in which 'some' or 'most' undergraduates demonstrated the use/understanding of ideas while doing the activity, and also remembered that knowledge in subsequent lessons. It is important to note that observations were made collectively so as to detect patterns, rather than taking into consideration single lessons' characteristics. Initially, it can be observed in Year 1 (Table 26) that some practical work lessons which were designed with aims focusing on developing knowledge (Plant Biology x 2) were successful, as undergraduates demonstrated an understanding of ideas (77% and 81% in the two lessons) while doing their activities. Undergraduates could also recollect important ideas and observed phenomena (62% and 73%) when asked in subsequent lessons.

In Year 2 (Table 27), the development of knowledge was not amongst the aims of one of the two lessons (Animal Nutrition and Zoology), where most undergraduates demonstrated an understanding and recollection of scientific information. Nevertheless, the importance of scientific ideas (ranging from fairly important to essential) implicitly suggests that the introduction of ideas was considered, as there was class discussion before the practical activity, about theoretical information required for the experiment. However, as seen in Year 2, class discussion about ideas before the practical activity was also observed in lessons where only a few undergraduates demonstrated an understanding of ideas and recollection of information when asked (Molecular Biology, Biochemistry 1, Biochemistry 2). Respectively, in Year 1 there was no class discussion before the practical activity for the two microbiology lessons, but there was evidence of understanding and remembering from 'some' undergraduates.

Comparing common characteristics between the only four Year 1 and Year 2 courses (Table 28) where understanding and remembering was observed in most undergraduates, it is evident that certain structural similarities could possibly contribute to the effectiveness of the practical work lesson, in terms of developing scientific knowledge and being able to later recall it. Providing detailed instructions on the practical work activity, along with explaining it orally, discussing its purpose and its underlying ideas prior to the experiment, are combined lesson characteristics observed in Year 1 Plant Biology lessons and Year 2 Animal Nutrition and Zoology. Additionally, class discussions following the practical activity – confirming what undergraduates saw, along with explaining observations – might contribute to the high percentages of undergraduates remembering information in subsequent lessons. Additionally, in Year 1 Cell Biology and Year 2 Immunopathology, ‘understanding’ percentages show that nearly half of the class could demonstrate understanding of ideas while working on their experiment; this indicates that structural characteristics which are similar to those in the successful practical work lessons mentioned earlier, could help undergraduates ‘do’ with ideas what was intended by members of staff.

In almost all Year 1 and Year 2 lessons where minimal understanding and recalling was demonstrated (20–39% and 9–38% respectively), it is noticeable that the development of knowledge was not amongst the aims intended for the practical work lesson. In Year 1, there was no class discussion before the practical activity, about ideas linked to the experiment; therefore, undergraduates could not use introduced theories while doing the experiment (Biochemistry, Microbiology, Histopathology). In Year 2, amongst the observed lessons where undergraduates’ understanding and recalling were limited, only in Pharmacology and Biochemistry did members of staff intend undergraduates to develop their knowledge. Additionally, even though class discussion took place in both lessons, practical work was not effective in the domain of ideas. In the rest, for practical work lessons where percentages of understanding and recalling were low, the development of knowledge was not regarded as important, and discussion of ideas before the practical was not attempted (Year 1: Microbiology, Histopathology; Year 2: Immunopathology, Biology of Diseases, Molecular Biology, Biochemistry).

Table 26

Year 1: Effectiveness of practical work based on design of practical work lessons

Only a few | Some | Most

Year 1

	Courses	Cell Biology	Biochemistry	Biochemistry	Microbiology	Microbiology	Histopathology	Plant Biology	Plant Biology	Biochemistr
Aims	Develop knowledge							x	x	
	Learn how to use equipment/SOP	x	x	x		x	x	x	x	x
	Understand the scientific approach							x	x	
Design	Detailed instruction	x	x	x	x	x	x	x	x	x
	Outline guidance									
	Importance of scientific ideas (Rate 4-essential;3-fairly;2-not very;1-unimportant)	2	2	2	1	2	2	1	2	1
Presentation	Activity proposed by teacher, no links made to previous work			x	x		x			
	Purpose of activity explained by teacher and explicitly linked to preceeding work					x		x	x	
	Class discussion about purpose				x			x		x
	Purpose apparent, follows previous work									
	Activity explained orally	x	x	x	x	x	x	x	x	x
	Written Instructions on projector	x			x		x	x	x	
	Worksheet	x	x	x	x	x		x	x	x
	Demonstration				x		x	x	x	
	Class discussion before the practical activity begins about equipment	x	x		x		x	x	x	
	Class discussion before the practical activity begins about ideas	x	x					x	x	
	Class discussion following practical activity confirming what we have seen	x	x	x	x		x	x	x	
	Class discussion following practical activity explaining observations							x		
	Understanding	47%%	44%%	skills	37%	39%	20%	77%	81%	skills
	Remembering	42%	37%	skills	37%	37%	18%	62%	73%	skills

Table 27

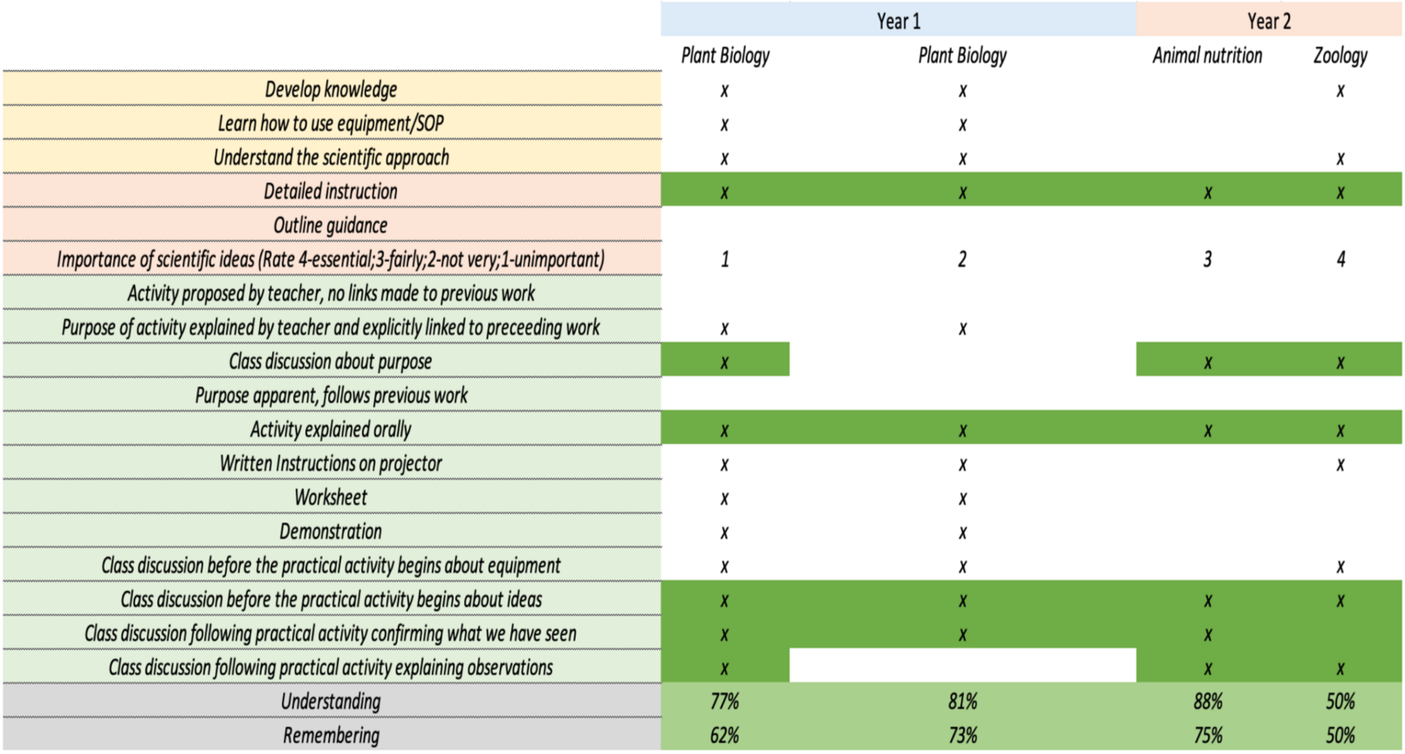
Year 2: Effectiveness of practical work based on design of practical work lessons

Year 2

	Courses	Immunopathology	Animal	Zoology	Pharmacology	Biology of Diseases	Molecular Biology	Biochemistry	Immunopathology	Biochemistry
Aims	Develop knowledge			x	x			x		
	Learn how to use equipment/SOP	x			x	x	x	x	x	x
	Understand the scientific approach			x		x		x	x	x
Design	Detailed instruction	x	x	x	x	x	x	x	x	x
	Outline guidance									
	Importance of scientific ideas (Rate 4-essential;3-fairly;2-not very;1-unimportant)	2	3	4	2	1	2	2	4	
Presentation	Activity proposed by teacher, no links made to previous work	x					x			
	Purpose of activity explained by teacher and explicitly linked to preceeding work					x				
	Class discussion about purpose	x	x	x	x			x	x	x
	Purpose apparent, follows previous work									
	Activity explained orally	x	x	x	x	x	x		x	x
	Written Instructions on projector	x		x		x		x	x	x
	Worksheet	x			x					
	Demonstration									
	Class discussion before the practical activity begins about equipment	x		x	x	x		x		
	Class discussion before the practical activity begins about ideas		x	x	x			x	x	
	Class discussion following practical activity confirming what we have seen		x		x		x	x	x	x
	Class discussion following practical activity explaining observations		x	x	x		x	x	x	x
	Understanding	38%	88%	50%	31%	38%	9%	12%	47%	18%
	Remembering	35%	75%	50%	27%	33%	9%	18%	43%	17%

Table 28

Effective practical work lessons based on structure.



	Year 1		Year 2	
	Plant Biology	Plant Biology	Animal nutrition	Zoology
Develop knowledge	x	x		x
Learn how to use equipment/SOP	x	x		
Understand the scientific approach	x	x		x
Detailed instruction	x	x	x	x
Outline guidance				
Importance of scientific ideas (Rate 4-essential;3-fairly;2-not very;1-unimportant)	1	2	3	4
Activity proposed by teacher, no links made to previous work				
Purpose of activity explained by teacher and explicitly linked to preceeding work	x	x		
Class discussion about purpose	x		x	x
Purpose apparent, follows previous work				
Activity explained orally	x	x	x	x
Written Instructions on projector	x	x		x
Worksheet	x	x		
Demonstration	x	x		
Class discussion before the practical activity begins about equipment	x	x		x
Class discussion before the practical activity begins about ideas	x	x	x	x
Class discussion following practical activity confirming what we have seen	x	x	x	
Class discussion following practical activity explaining observations	x		x	x
Understanding	77%	81%	88%	50%
Remembering	62%	73%	75%	50%

Below, a selection of conversations shows undergraduates demonstrating an understanding of the main ideas important for the practical activity, whereas others show the opposite.

Evidence of Undergraduates Demonstrating Understanding of Main Ideas

Sex determination from cells

Researcher: What is amelogenin ?

Group of students: It's a gene. We do not know. It's the difference between man and woman.

Researcher: How do you determine sex?

Group of students: It has to do with the length of the gene, something like that. We will ask.

Determination of creatinine by colorimetric methods

Researcher: Since we see that there is dehydration in our patient, what do we need to look for?

Student: Sugar

Researcher: Because of?

Student: Diabetes!

Researcher: That's right.

Interpreting results for anticoagulant monitoring

Researcher: Have you started interpreting the results?

Group of students: There is something wrong with this patient for sure, but we are not sure what…

Researcher: What do you expect? What is warfarin and does warfarin work from the first day?

Group of students: It is a blood thinner. No, I do not remember what and how, but I am sure it takes a while. It takes approximately 3–4 days.

(They did not remember the scientific term for blood thinning, which is anticoagulation)

Researcher: What about sample B?

Group of students: It looks okay

Researcher: Don't you think the reading is low?

Group of students: Yes, yes, you are right, it's low.

Researcher: Now, for sample D and E. It shows that warfarin stopped working. Why is that?

Group of students: Maybe the patient stopped taking their drugs.

Researcher: It is possible, yes. So, why do we give heparin first and then warfarin?

Group of students: [Silent]

Researcher: It acts faster. We want to give them something to boost them.

Group of students: Ah! Yes! And for long-term use we give them warfarin.

Researcher: That is right.

Researcher: Lastly, what influences the action of warfarin?

Group of students: There is possibly something wrong with the patient's diet.

Researcher: Right. So what vitamin affects warfarin?

Group of students: [Silent] They need to be careful not to overdo it with…

Researcher: K possibly? What veggies are high in vitamin K?

Group of students: Kale!

[Meanwhile, undergraduates finish the procedure and ask demonstrators whether they can confirm their results]

Preparing cells for immunofluorescence microscopy

Researcher: What is the purpose of secondary antibodies?

A small group of students: They bind to primary antibodies.

[Most of the undergraduates, apart from the usual group that demonstrated high abilities in conceptual understanding, did not know that a secondary antibody binds to a primary antibody.]

Evidence of Undergraduates Lacking Understanding of Main Ideas

Preparing a PCR sample

Researcher: Do you know what DNA denaturation is?

Student: Oh! That's a long word. It is correlated with PCR, right?

Researcher: Yes, there is a denaturation phase during PCR.

Student: Right! I remember something about it but I will read about it later. I will remember what I did now and I will check it in the book.

Researcher: Do you know why we amplify DNA?

Student: That's what PCR does, yes?

Researcher: Correct

Student: To have enough quantity to measure it? I am not sure, let me check the protocol. Ah! Yes.

Observing findings after using the Gram staining methodology

Researcher: Do you know what a Gram positive stain is?

Group of students: Well, it has to do with the cell walls and thickness, something like that. We did it in the lectures, I am not so sure but I will check it, give me a minute.

[There was no discussion at the end of their practical activity. Most undergraduates got it wrong, and those who did not ask for guidance left the laboratory with wrong answers.]

Interpreting results for anticoagulant monitoring

Researcher: What does it mean when coagulation time increases?

Student: Warfarin is working.

Researcher: So what happens to the viscosity of the blood?

Student: It decreases. It becomes thin.

Researcher: And what is the risk?

Student: Developing a thrombus.

Researcher? Really? Even though the blood is thin?

Student: Oh no!

Observing bacterial cultures

Researcher: Have your broths worked?

Student: Yes, they are cloudy.

Researcher: Hmm... Why?

Student: They have bacteria in it.

[Demonstrator steps in to explain the theory behind it.]

Liver function tests

Researcher: The bilirubin numbers are high. What does bilirubin do?

Group of students: It makes poo brown.

Researcher: Okay… because of the…?

Group of students: Is it haemoglobin?

Researcher: Bile

Determination of creatinine by colorimetric methods

Researcher: What about the calcium levels? Which vitamin is related to calcium?

Student: Vitamin C?

Researcher: It's vitamin D.

Important Remarks

Although less than half of undergraduates, in most cases, could demonstrate an understanding of the ideas the lecturers intended them to use in the practical activities (as observed in Table 25), in most lessons, after the experiment there was a discussion where the lecturer explained what to remember about what they saw, along with the main findings. This allowed undergraduates to understand what they were seeing, and enabled them to identify which ideas they had to use in order to understand the experiment. In addition, throughout the practical activity, undergraduates were guided by members of staff to help them proceed with the experiment and the steps that had to be taken. Whilst all undergraduates demonstrated the ability to complete the activities, the importance of scientific ideas throughout the experiment, as suggested in Table 13, was low and did not affect them.

Data Analysis D – Interviews with Members of Staff at the School of Life Sciences

Findings from Section D,C and B will be presented in an attempt to answer Research Question 2:[Based on members of staff's perceptions and reflections] Are practical tasks effective in enabling undergraduates to do and/or learn what was intended? If yes, when?

In this section, findings from the semi-structured interviews with 14 members of staff at the School of Life Sciences are presented and thematically analysed, in order to answer the research questions of this study. Members of staff teaching in the laboratory included lecturers, technicians and postgraduate demonstrators. Their contribution to the teaching of practical work lessons was significant; therefore, it was important to interview them to obtain their perceptions of practical work, what they believed undergraduates were learning, and what their main goals were when planning and designing practical tasks. Common themes were identified in all interviews; these are analysed below, including a selection of the most representative quotes.

Table 29
Main themes and sub-themes from interviews with members of staff

Main Theme	**Sub-themes**
Affective value	1. Anxiety and Confidence 2. Interest 3. Interaction
Assessment	
Aims	1. Career 2. Hands-on 3. Skills 4. Independence and Progression
Benefits	1. Reinforcement 2. Remembering 3. Visualising
Obstacles	

Effectiveness	1. Prerequisite learning 2. Repetition 3. Structure of practical work lessons 4. Support by members of staff 5. Combining lectures and practical work
Taking advantage of resources	
Successful lesson	

Theme 1: Affective Value

Anxiety and Confidence

Initially, when academic staff were asked about the affective value of practical work, they explained that the laboratory environment, along with the experience of doing practical work, can trigger anxiety for many undergraduates. This is due to the nature of the lesson, and the overwhelming information that has to be processed in a limited amount of time:

> *Labs are stressful to a number of students because they are intimidated.*
>
> Staff 10

Moreover, academics further explained that the build-up of stress affects undergraduates' performance, and they need to be slowly encouraged in order to feel more comfortable, so as to perform better and start taking the initiative while doing experiments:

> *Some students are so stressed when they are in the laboratory that you have to help them build their confidence in order to perform well.*
>
> Staff 11

However, even though undergraduates spend, as a minimum, three hours a week on practical work, academic staff believed that the nurturing of confidence is hindered, since undergraduates do not spend enough time in the laboratory; therefore, they cannot practise enough to perfect their skills.

> *Students do not do enough practical work to have increased confidence, and that puts them off.*
>
> Staff 2

For this reason, to tackle this problem , some members of staff decided to ensure that undergraduates left the laboratory knowing that they had achieved something. Getting feedback on their results, and knowing the right answer before they went home, were deemed as essential, as undergraduates would then be able to reflect, use the right answers, and study further in order to understand what they did in the laboratory. They explained that:

> *We always ask students to present us their results before leaving, so they can build confidence that they have achieved something.*
>
> Staff 5

> *You give them gentle encouragement, which builds their confidence up so they can learn how to be autonomous. Practical work is intimidating enough already.*
>
> Staff 3

During the discussion, they also acknowledged that undergraduates face a set of expectations concerning safety. These must be met in order for practical work to run smoothly in the laboratory, and this overwhelms them, since they have to learn to be autonomous and responsible.

> *Health and safety is at stake, they need to be careful and this scares them.*
>
> Staff 5

> *Some students find the weight of responsibility heavy.*
>
> Staff 9

> *They are stressed if there is too much information. It overwhelms them.*
>
> Staff 4

Moreover, confidence was also linked to independency, and academics commented that undergraduates feel uncertainty in the laboratory; therefore, they always needed someone to support them:

> *When they need to think, they panic and they ask the demonstrators for guidance.*
>
> Staff 14

Interest

Many staff members admitted that practical work, as an activity, will not necessarily make undergraduates interested in the subject they are studying, if they are not personally invested in it:

> *Practical work cannot make students interested, you cannot switch them on.*
>
> Staff 10

Undergraduates' interest, as two members of staff further explained, is reflected in attendance; therefore, there needs to be promotion of the practical work lesson, to encourage undergraduates to participate. In addition, they noticed that undergraduates do not clearly understand the benefits of practical work, and potentially its role in the subject they have chosen to study. Thus, members of staff are required to promote laboratory work in order to capture the attention of undergraduates.

> *We cannot force them to attend practical work lessons. The value of practical work should be promoted more, because students underappreciate what practical work is.*
>
> Staff 11

> *Some students enjoy practical work, but judging by the lack of attendance when it is not assessed, that does not seem to be the case for all of them.*
>
> Staff 2

> *If we can give an introduction of the practical before the lecture just to sell the practical, it will encourage them to come to the practical.*
>
> Staff 7

Furthermore, they added that the affective value of practical work depends greatly on personal motivation and enjoyment of the lesson.

> *If it motives them, they will put the effort in doing it.*

Staff 11

> *If they do not enjoy it, they will not enjoy it.*

Staff 8

> *Practical work inspires students who have a plan. I do not think it is practical work that makes students pick science, apart from those who will pursue a lab-work-based career afterwards.*

Staff 9

Staff members also mentioned that they can clearly distinguish undergraduates who are keen on learning in the laboratory from those who are not interested:

> *Students who like practical work and are truly interested in learning stick together and stay in groups so they can work together.*

Staff 9

> *You've got to like science. Practical work is not going to make it fun for you, it is tedious work. Students who have a personal interest are already prepared when in the laboratory.*

Staff 1

Interaction

Another theme that emerged in the discussion was the interactive nature of practical work and how this differentiates it from lectures, in the sense that undergraduates are allowed to talk with their peers and work together. This was a factor that made practical work likeable for undergraduates.

> *It gets you out of the lecture. It allows students to work together and interact.*

Staff 4

> *Shared experience with other students makes it more fun.*

Staff 1

One of the important points discussed, regarding the interactive nature of practical work, was that undergraduates can take part in their learning instead of passively listening to lectures, and this makes teaching easier for lecturers.

> *They do not have to sit and listen to a lecture, so it makes it more relaxing for them.*
>
> Staff 4

> *Science can be factual and dull, so practical work is the fun bit. The hands-on part. We want more practical work because it's easy to teach something in the context of a practical work lesson rather than trying to get their interest by talking.*
>
> Staff 1

Theme 2: Assessment

The second theme that arose is indirectly related to the affective value of practical work, in the sense that undergraduates see it as a form of external reward, whereas members of staff use it as a way to identify successful learning. It was evident from the discussions that assessment played a major role in attendance, and whether undergraduates paid attention in the laboratory.

> *If practical work is not assessed you are likely to have less attendance. The reason is that students are exposed to a lot during their degree, so they prioritise on grades since they have limited time.*
>
> Staff 2

> *If the experiment is linked to an assignment, they know they have to produce good results that they will be able to use later. They certainly lose focus if you take off the assignment.*
>
> Staff 8

> *They seem to just suddenly put effort into things which give them marks. It's all down to the marks they are getting.*
>
> Staff 3

In the department, undergraduates were assessed in different ways, with the main aim being to support their learning. Some staff members even emphasised giving on-the-spot feedback, to allow undergraduates to leave the laboratory with the correct answers in their mind.

> *Lab reports help us identify whether students understood the underlying theories of what they did. Sometimes we even walk around in the laboratory and we can see what students are doing, and we understand what they need further support and help in.*
>
> Staff 2

> *Sometimes we give them MCQs [multiple-choice questionnaires] at the end of the practical as part of a coursework, and we discuss the results with them before they go home so that we can ensure that they know the correct answers. Anyway, they usually collaborate during the in-class assessment, so this does not really assess whether they know.*
>
> Staff 3

> *I do not give them an assessment during the practical work lesson because that is destructive. In their submissions, there will be elements where they will be encouraged to show their understanding of the experiment. By looking at that assessment I will understand whether delivery of the lesson was successful.*
>
> Staff 5

Some members of staff admitted that they do not solely rely on formal assessment to understand whether their class has learned what they intended them to learn. Progress is evident week by week, and this is identified in the laboratory.

> *I do not care if they get the correct or wrong results during the experiment, as long as they understand what the result is about and why it was wrong or right in the first place.*
>
> Staff 8

> *There are so many different ways of assessing them. It is the progressive side of it, you can see them getting more comfortable with the equipment with time, but you can also test them on paper. You can see instantly and informally whether they are progressing and whether they have achieved something from practical work. The*

> *experiment will work only if they used the equipment right, so in a way, this is some sort of assessment.*
>
> Staff 4

Theme 3: Aims of Practical Work

The interviews revealed that members of staff had common views on the aims of practical work, along with the impact of those aims in undergraduates' motivation. Views focused on practical work being a hands-on training tool that allows undergraduates to pursue a career in sciences, since they are developing their skills while they start being more independent in the lab and they progress through the years.

Career

Most members of staff felt that the purpose of practical work is to prepare and train undergraduates for industry; as a result, this motivates them, as they feel that they can use what they learn later on. Some examples are presented below.

> *We have the responsibility to try and produce new scientists because they are a great value to the society. When we give them the opportunity to do practical work, they can understand what they like and decide their future career and what avenue they want to pursue in their future.*
>
> Staff 11

> *Five minutes here, five minutes there, we are not trying to give them competency using the machines because when they go to the industry, they will most probably find a different machine. We are trying to familiarise them with the equipment so they can go to an interview and say that they have seen something like that before. It gives them an edge. They will have something to talk about with future employers.*
>
> Staff 2

> *Practical work gives them insight about what the profession is really about, so their expectations are closer to reality. Putting experience on their resumé can help them in their job prospects.*

Staff 3

> *The early career of a scientist is at the bench. Practical work prepares them for a job. The outside world has come to the university world.*

Staff 5

It was clear that members of staff were aware that undergraduates were more motivated when they knew that they could apply what they had learned in real-world settings.

> *Students need to understand that what they are learning will be used later on, and when they realise that, they learn and engage more. If you make the lesson applicable to real-life scenarios then everything is put in context.*

Staff 9

> *Practical work gives students the spark in their brain, and they know whether what they are doing is something they want to do in their career.*

Staff 10

Hands-on

‘Hands-on’ was an umbrella term that most members of staff used to explain the general goal of practical work. Specifically:

> *We are training students in a practical subject. Practical work is a hands-on experience and is crucial, particularly in early years where we train them to do things. Moving forward to Year 3, they are able to design their own work based on what they learned.*

Staff 10

> *It will be disastrous to train a scientist without practical work, it is hands-on.*

Staff 14

> *We want practical work because it takes authentic learning almost to a hundred per cent. It kills so many birds with one stone. If we think about the model of apprenticeship, you basically learn by doing, by having your hands-on. They are exposed in that environment.*

Staff 2

Skills

The development of skills was one of the most important goals that members of staff wanted to achieve through practical work. These skills ranged from subject-related to soft skills, which allow students to build resilience in the laboratory.

> *One of the main goals of science education at university is to produce more scientists, and those scientists need those lab skills. Having that formal training in techniques is important because they start understanding what those techniques are about. We need them to be able to do something, but also understand and troubleshoot when that something does not work.*
>
> Staff 11

> *If you look in scientific journals, all those pictures are the best images that the researcher ever got of that particular test. Students cannot see the mistakes and failures, so getting experience in the lab helps them understand that sometimes tests do not work. It gives them the opportunity to see what science is like and trains them in being resilient.*
>
> Staff 1

> *We want to have practical work in the curriculum so that students can get good at doing things in the lab. Introduce them to a range of techniques. We can all go and read a book, but we will have no idea how to do things in the laboratory.*
>
> Staff 2

> *We want them to learn that science is a team thing. It is the way you can put ideas on the table. We want them to learn the scientific process.*
>
> Staff 6

Some members of staff also emphasised that the development of skills is a curriculum requirement for accredited programmes.

> *Some programmes have requirements of practical work in terms of learning methodology, but also developing transferable skills like working in teams, analysing data, observing, being creative. Health and safety, ethical conduct and budgeting is also something that they need to have in their toolkit.*

Staff 9

Independence and Progression

It was evident that members of staff were referring to the aims of practical work based on the undergraduates' year of study. As they were progressing to senior years, undergraduates were described as independent and more comfortable; they believed that this verified the effectiveness of practical work.

> *In the first year we tell them exactly what to do, we show them what to do so that they develop good habits and develop their skills. We are helping them develop their investigative skills, and ideally by the time they become second and third years, they will be able to put everything together.*

Staff 10

> *In the first year we want to make them slow down and train them. In second year we have modules that assume that they got the right skills, so we do set them problems that they will work on in a series of labs. They will get more out of it if they do it autonomously and discover for themselves. In order for them to do that, they need to know the basics, so first year is for training.*

Staff 2

> *In Year 1, students, inevitably, have cookbook experiments because they do not have the confidence or skills to be more independent. If they were, we would have some serious accidents. When they get to the third year, it's not that you leave them roaming free in the laboratory, but you can possibly give them a task and let them do elements of experimental design. You cannot leave them too free because the risk is that you lose the learning point, because they will struggle to do the problem-solving on their own. You can introduce elements of self-driven experimental design in Year 3. They need to be ready for their research projects for their final year.*

Staff 5

Theme 4: Benefits of Practical Work

Answering the question of whether practical work is an effective practical tool, members of staff emphasised that it benefits undergraduates to learn and understand science. Again, practical work was regarded as a teaching tool that allows them to support lectures, in order to give undergraduates a holistic experience in learning science.

Reinforcement

In the interviews, many members of staff used the word ‘reinforcement’ to describe the effect practical work had on undergraduates’ learning experience.

> *Students get a better understanding of how things link together and how experiments reinforce the theory, rather than learning isolated theory and trying to make connections.*
>
> Staff 11

> *Using the same techniques in different theoretical contexts can help students to develop skills while reinforcing the theory they learn in the lectures.*
>
> Staff 2

> *Doing practical work while introducing them to the theory helps in reinforcing it. They make connections and they realise what they have learned while doing experiments.*
>
> Staff 9

Remembering

Another benefit of practical work, according to members of staff, was that it helped undergraduates to better remember what they had learned.

> *The fact that they do experiments in the laboratory so close [in time] to their lecture, along with the theoretical introduction we might give in the laboratory, is useful because otherwise they forget about everything they do and everything they heard in the lecture theatre.*

Staff 2

> *People learn more by doing. It helps them remember things if they do it in a constructive way, rather than if you stand in a lecture theatre and talk to them.*

Staff 3

The interviews indicate that practical work was concerned with allowing undergraduates to see something in real life. Staff members believed that this contributed to the reinforcement of theory, and helped undergraduates remember better.

> *Students get a chance to experience all those things that otherwise they would not be able to see in lectures.*

Staff 11

> *It is as simple as giving them a visual cue to the experience, and other times it is just taking what they learned in the lectures and connecting it to actual phenomena, rather than them having an abstract idea from the book.*

Staff 13

> *Practical work takes information from books and makes things real in the laboratory. Some principles are explained better when the student can see with their own eyes what the textbook cannot show really well. They can see microorganisms, they can see DNA!*

Staff 2

> *It helps you visualise the theory. If you are doing a dissection you can see a diagram but going through it, you can learn anatomy by looking at something, visualising it, touching it. It makes better sense because you are in the environment where you are immersed in, doing that task.*

Staff 6

Theme 5: Obstacles

While discussing the effectiveness of practical work in the laboratory, it was crucial to talk about factors that hinder learning and challenge the flow of a lesson.

> *The number of students in most practical sessions is too big. We cannot coordinate the class and we cannot give advice to each and every student in the lab. It is impossible to do inquiry-based experiments. It has to be cookbook.*
>
> Staff 10

> *The issue with having more practical work is financial. If we could have more practical work, then we would be able to do shorter experiments that would allow the students to understand the theory better and take their time. They are overwhelmed because they need to do too much at once.*
>
> Staff 4

> *I wish that students did not have to learn so much theory in such a wide area of sciences and they could just learn what can be applicable later on. This would allow them to focus more. Some steps on the protocol, for example, are done by technicians. Students cannot prepare primers, it's too expensive. When you start doing an experiment from step 11 onwards, well, you do not really engage with the experiment, do you?*
>
> Staff 6

> *If we do not force them to study before the experiment, they go into the lab and they do not know what they are doing. Then they leave and they say they will study at home. By the time they go home, they do not remember what they did in the lab.*
>
> Staff 7

Theme 6: Effectiveness

Talking about the effectiveness of practical work, and what members of staff had experienced throughout the years in their lessons, gave them the opportunity to realise, through trial and error, what works, and what allows students to learn better while doing experiments. Five sub-themes arose from the discussions, which can be regarded as factors that contribute to how effective practical work can be.

Prerequisite Learning

Members of staff realised that undergraduates who prepare and read the protocols and underlying theory before entering the laboratory are able to engage and perform better, as they do not get overwhelmed with new information. Prerequisite learning, they stated, is not mandatory, and undergraduates will probably be able to run the experiment without any prior knowledge; but undergraduates are expected to undertake this learning.

> *We have learning assumptions, so we ideally want students to read notes from the lectures and then come to the lab. We assume that they will be ready by the time they start doing their experiment. They will get much more from the practical lesson if they are ready.*
>
> Staff 10

> *If you just had practical work by itself, you would not have any learning because you need some background information to do an experiment. Science is built on bases of knowledge and is being built up generation after generation, so you cannot expect someone to function without the underpinning knowledge. The same goes for practical work, you need baseline knowledge on which you are building ideas, and the experiments do not have to be about what was exactly taught in the lectures, as long as the foundations of the experiment are rooted on what students have been taught.*
>
> Staff 11

> *Practical work is like solving a puzzle. They have to join the dots. If they read about the theory, they will have enough pieces to solve that puzzle. If they come unprepared, they will stay behind and they will struggle. They can perform an experiment just fine if they read the instructions, but I doubt they will understand why they are doing what they are doing.*
>
> Staff 2

> *I do not think they need to know anything before coming in the lab. Everything is in the lab book, they can read what they need while doing the experiment. They do not need to know lots of information in order to pour liquids and proceed with the experiment. They get opportunities to be involved regardless.*
>
> Staff 4

> *Pre-learning envelops the practical work lesson, and there is the learning after the lab. They are interlinked. It's a sequence.*
>
> Staff 7

Repetition

Members of staff commented on how important repetition is in order for undergraduates to master a skill in the laboratory. Since the development of skills was one of the aims of practical work, it contributes to its effectiveness as a practice.

> *They need the training, if you do not do something for a long time you forget the little details, and eventually your experiments and tests start being inaccurate.*
>
> Staff 11

> *In order to learn skills, there has to be constant reinforcement. There should be more practical work sessions using similar techniques every week, so that students can build up and familiarise themselves with equipment. Repetition is key.*
>
> Staff 1

> *Most students develop year by year with more practice and more experience, and they become competent.*
>
> Staff 7

Structure

The structure of the lesson and the design of the practical work were regarded as crucial by some members of staff. They believed that they have a great influence on whether practical work will be enjoyable and effective for undergraduates, and this relates to how well-structured a lesson is in the laboratory.

> *As long as it is clear, what you want from them, they enjoy it.*
>
> Staff 1

> *The practical work lessons that run well are normally the well-designed ones. Designed in such a way that each one in the series follows on from the next and it creates a story. You can always design case studies which are related to real-life situations and give them introductions before the experiment.*
>
> Staff 6

> *A well-designed practical is one that is placed in context and also prepares students before starting the experiment. Giving them the information they will need before starting is important, as well as giving them the answers they need to hear before leaving.*
>
> Staff 4

> *The structure of the laboratory lessons should be interactive. People want to have fun in the laboratory and we want to keep them enthusiastic. We should provide them with a short introduction about the theory, and slowly and progressively give students more autonomy. You can see that students can cope well with that, and that their confidence in what they are doing gets better.*
>
> Staff 10

Support by Members of Staff

It was evident that along with the structure of practical work lessons, members of staff valued and recognised the importance of having technicians and demonstrators walking around the laboratory during the experiments. Everyone plays their role in the laboratory.

> *Some students come in the lab unprepared. Some of them did not attend the lectures. If you make sure that the demonstrators and technicians are around to help them connect the dots, giving them direction, then you know that they will be able to understand what they are doing. Even when students know the correct information, they need someone to confirm that they are on the right path, they need scaffolds.*
>
> Staff 6

> *The practical work lesson is like a show. You need to introduce them to things. It's choreographed. The demonstrators and I show them things, talk to them about theories, and we check with them that they are understanding what they are doing. If you just let them do things on their own, you are going to lose time, and you really need to guide them so you can make sure that they won't miss the point of the experiment.*
>
> Staff 4

> *Demonstrators and technicians should intervene during the experiment, so as to let students connect theory with practice in that moment when they start wondering "What is this for?". There is no way they can get the theory by just doing experiments. The lecturer must know when to talk and what to say. They should be reminded about what is the experiment for and about.*
>
> Staff 1

Combining Lectures and Practical Work

The final factor that members of staff considered as important for the effectiveness of practical work is that lectures should complement practical work.

> *Lectures and practical work should be combined. They should be done complementarily. It is unusual for practical work to stand alone.*
>
> Staff 10

> *Practical work needs to back up lectures. You have to help them fill the gaps, conceptually. If they know they theory, they are switched on, they participate.*
>
> Staff 11

Theme 7: Taking Advantage of Resources

All members of staff agreed that they cannot control how undergraduates choose to study at university. They believed that a well-structured curriculum can provide them with different opportunities that they need to take advantage of.

They are old enough to start being responsible for their training. This is what a science degree is. Training for the industry.

Staff 8

They have to motivate themselves to get the most out of being at the university. We provide it all and they have to take advantage of everything that is on offer.

Staff 10

The most significant dividers of high achievers and those who do not do well in their degree is personal interest in science. We should not expect practical work to be the panacea of science, it is there as an activity to train them to be scientists and they should take advantage of that. It is one of the tools in the toolbox, but you can only motivate them up to a point. You are building on their core motivation. If their core motivation is that they are keen to become a researcher or a scientist, you can go long way with it. If their core motivation is that "I want to do a degree before finding a job", then you cannot do anything about it, unfortunately.

Staff 5

Practical work is effective and benefits those who want to be benefited. If they want to make the most out of their degree, they will find ways and it will work.

Staff 3

Theme 8: Successful Learning

At the end of the interview, the researcher invited members of staff to think of ways in which they know that practical work was successful. They all responded in very similar ways.

It becomes obvious. They ask questions, they want to know more, they are engaged.

Staff 11

By the end of the practical work lesson, by looking at the cohort and the results, you will have a sense of whether they managed to learn something. If the laboratory is quiet, it means everyone is working and it is going well.

Staff 1

> *When you start seeing panicky faces, hazards, damages, people running out of time, you know that you did something wrong with the lesson plan.*

Staff 6

> *A successful practical is when someone asks questions outside of the protocol and the material taught. That way you can see that they have started processing information and linking theory with the experiments. That is when you know that there is a high possibility that they will go home and read, you got them interested.*

Staff 4

Data Analysis E – Undergraduates' Meaningful Learning Questionnaire

Findings from Section E and F will be presented in an attempt to answer Research Question 3: Does practical work contribute towards meaningful learning? If so, to what extend does the affective value contribute to that learning?

A questionnaire by Galloway and Bretz (2015) was adapted for the purposes of this study; it was distributed to Year 1 and Year 2 undergraduates at the beginning of the semester before any practical work had taken place for that year (pre-questionnaires), and at the end of the semester (post-questionnaires). The aim was to understand undergraduates' expectations and experiences related to the cognitive, cognitive/affective, and affective dimensions of their learning whilst undertaking practical work in the laboratory; and thus, to assess whether meaningful learning was taking place.

As shown in Table 30, pre-questionnaires were collected from Year 1 (n=166) and Year 2 (n=90), and post-questionnaires were collected from Year 2 (n=139). This allowed the direct comparison of undergraduates' experiences at the very beginning of their studies in their first year, with the expectations of those at the beginning of their second year, who had already experienced one full year of practical work in the laboratories. Moreover, the experiences of Year 1 undergraduates at the beginning of the semester were also compared to questionnaires acquired from Year 2 undergraduates at the end of their first semester, to identify any changes in the expectations of Year 2 undergraduates in comparison to Year 1 after 16 months. Lastly, questionnaires collected at the beginning of Year 2 were directly compared to questionnaires collected at the end of the second-year semester, to identify whether undergraduates' expectations of their second year had changed in a semester. Based on Galloway and Bretz's research (2015), time was a factor that had an impact on undergraduates' experience on practical work, given that their transition from Year 1, with limited prior laboratory experience, to Year 2, involved a "high attrition rate" experience (Galloway & Bretz, 2015, p. 1155). Negatively keyed items (see Q2, 3, 5, 8, 11, 13, 15, 17, 18, 19, 20, 27, 28 in Table 31) were reversed-coded so that a high score would indicate a positive belief towards meaningful learning. In this case, for all of the data collected, the mode and median were the same, 3, showing the undergraduates had high expectations for their laboratory experience.

Table 30
Questionnaire comparisons from data collected at the beginning of the semester for each year (Pre-) and at the end of the semester (Post-), to assess meaningful learning

Year 1 Pre-test	**Year 2 Pre-test**	**Difference 12 months**
Year 1 Pre-test	**Year 2 Post-test**	**Difference 16 months**
Year 2 Pre-test	**Year 2 Post-test**	**Difference 4 months**

Table 31

Meaningful Learning questionnaire with negatively-keyed items reversed (adapted from Galloway & Bretz, 2015)

1	Learned science that will be useful in my life.
2	~~*Worried~~ (I did not worry) about finishing on time.
3	*Felt ~~unsure~~ (sure) about the purpose of the procedures.
4	Experienced moments of insight.
5	*Was (not) confused about how the instruments work.
6	Learned critical thinking skills.
7	Was excited to do science.
8	*Was (not) nervous about making mistakes.
9	Considered if my data makes sense.
10	Thought about the function of humans/animals/plants/cells/atoms/molecules.
11	*I (did not ~~felt~~ feel) disorganised.
12	Developed confidence in the laboratory.
13	*I was (not) worried about getting good data.
14	Thought the procedures to be simple to do.
15	*I was (not) confused about the underlying concepts.
16	"Got stuck" but kept trying.
17	*I was (not) nervous when handling chemicals/samples.
18	Thought about science I already know.
19	*I was (not) worried about the quality of my data.
20	*I was (not) frustrated.
21	Interpreted my data beyond only doing calculations.
22	This statement is used to discard the survey of people who are not reading the questions. Please select 'strongly disagree' for this question.
23	Focused on procedures, not concepts.
24	Used my observations to understand the behaviour of humans/animals/plants/cells/atoms/molecules.
25	Made mistakes and tried again.
26	Was intrigued by the instruments.

27	*I (did) not (feel) ~~felt~~ intimidated.
28	*I was (not) confused about what my data mean.
29	Was confident when using equipment.
30	learned problem-solving skills.
31	Understood theory better through practical work.
32	Gained practical experience for future jobs.
33	Could recall and remember concepts because of practical work.

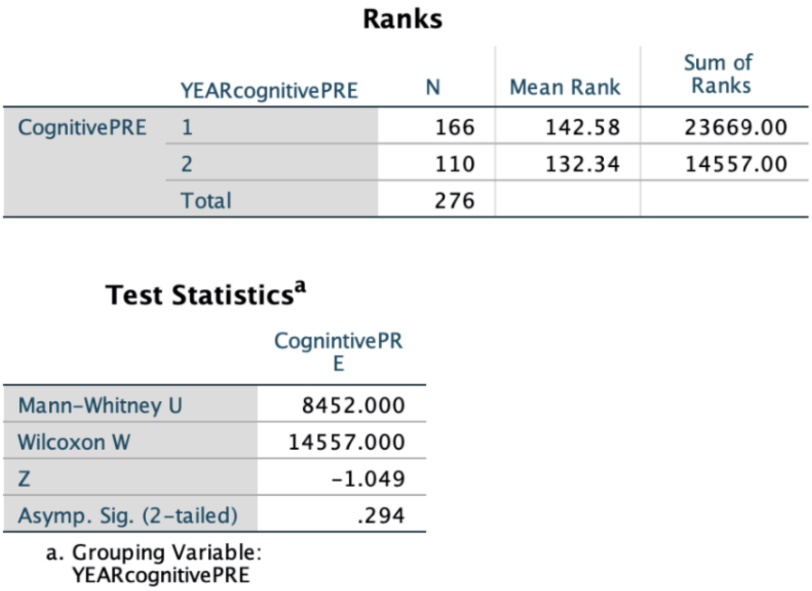
Year 1 pre-test Year 2 pre-test

Ho: There is no difference between Year 1 and Year 2 undergraduates' expectations about practical work

In the SPSS Tables 32 and 33, results of the Mann–Whitney U test are presented. Since the p value is 0.294 for the cognitive and 0.126 for the affective domain, there is no evidence to reject the null hypothesis. The medians of the two samples (both 3) are not significantly different, showing that both Year 1 and Year 2 undergraduates have similar expectations at the beginning of the semester, which contribute to meaningful learning in the cognitive and affective domains.

Table 32

Year 1 and Year 2 pre-tests for the cognitive domain: Mann–Whitney U test



Ranks

	YEARcognitivePRE	N	Mean Rank	Sum of Ranks
CognitivePRE	1	166	142.58	23669.00
	2	110	132.34	14557.00
	Total	276		

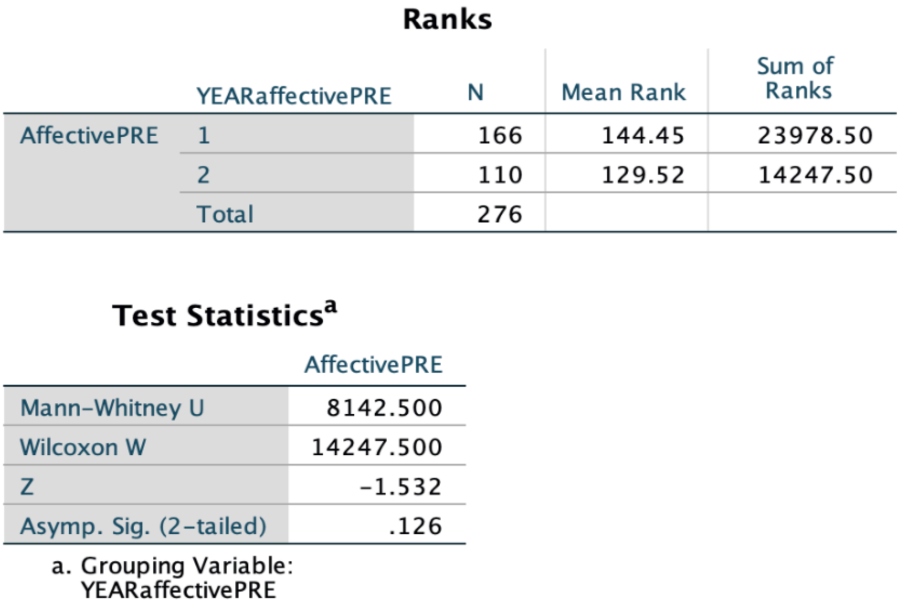
Test Statistics[a]

	CognintivePRE
Mann–Whitney U	8452.000
Wilcoxon W	14557.000
Z	-1.049
Asymp. Sig. (2-tailed)	.294

a. Grouping Variable: YEARcognitivePRE

Table 33

Year 1 and Year 2 pre-tests for the affective domain: Mann–Whitney U test



Ranks

	YEARaffectivePRE	N	Mean Rank	Sum of Ranks
AffectivePRE	1	166	144.45	23978.50
	2	110	129.52	14247.50
	Total	276		

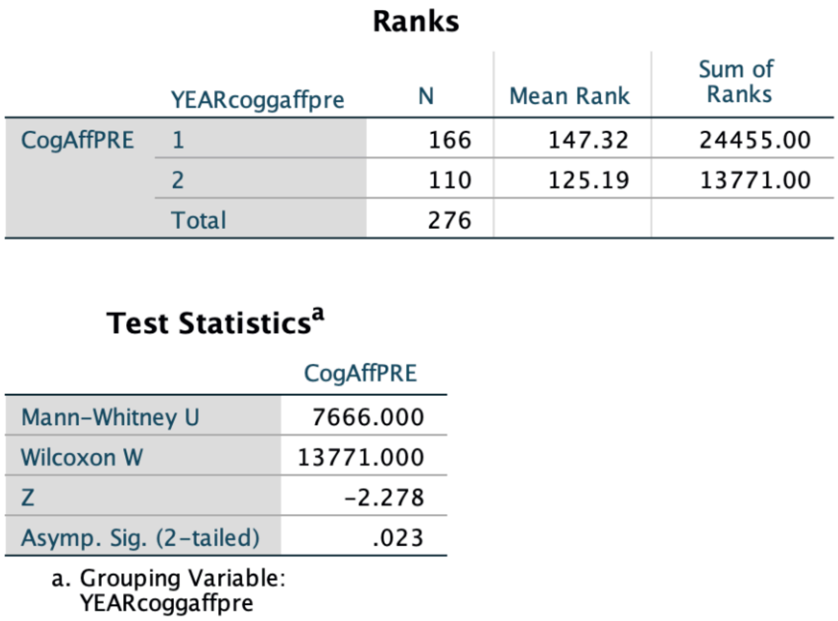
Test Statistics[a]

	AffectivePRE
Mann–Whitney U	8142.500
Wilcoxon W	14247.500
Z	-1.532
Asymp. Sig. (2-tailed)	.126

a. Grouping Variable: YEARaffectivePRE

Table 34

Year 1 and Year 2 pre-tests for the cognitive/affective domain: Mann–Whitney U test



Ranks

	YEARcoggaffpre	N	Mean Rank	Sum of Ranks
CogAffPRE	1	166	147.32	24455.00
	2	110	125.19	13771.00
	Total	276		

Test Statistics[a]

	CogAffPRE
Mann–Whitney U	7666.000
Wilcoxon W	13771.000
Z	-2.278
Asymp. Sig. (2-tailed)	.023

a. Grouping Variable: YEARcoggaffpre

Concerning the cognitive affective domain (Table 34), the p value of 0.023 indicates that the null hypothesis must be rejected, since the medians of the two samples are significantly different from each other, with Year 1 pre-test questionnaires having higher mean ranks of questionnaire scores than those of Year 2. This reflects that Year 1 undergraduates' expectations, which contribute to meaningful learning in the laboratories, were higher than for Year 2 undergraduates, who scored lower in expectations for the upcoming year.

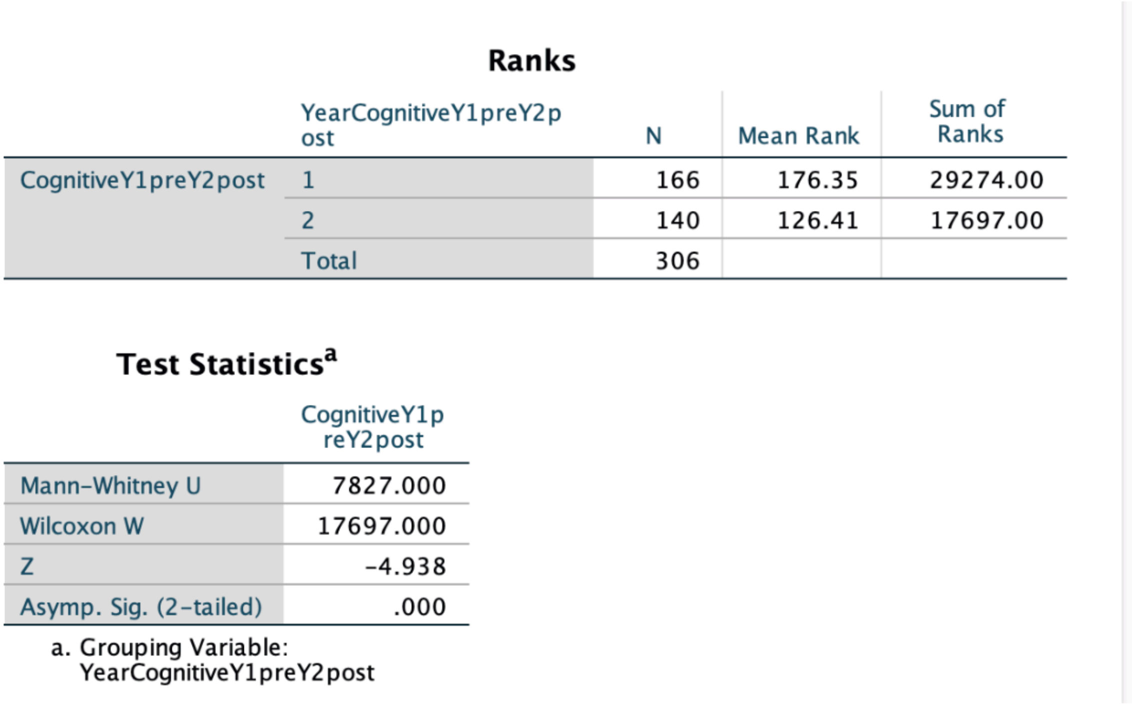
Year 1 pre-test Year 2 post-test

Ho: Year 2 students' experience, as reported in the post-questionnaire, matches students' expectations in the pre-questionnaire

The comparison of Year 1 Pre-tests and Year 2 Post-tests (Table 35) shows that for the cognitive domain the null hypothesis is rejected, with a p value of 0.000, since the means of the two samples are significantly different from each other. In fact, Year 1 undergraduates had higher expectations for the cognitive domain, whereas Year 2 students' expectations were not met, based on their experience with their second-year semester. On the contrary, the significance values for the affective (Table 36) (p=0.211) (median Y1 2.75–Y2 2.63) and cognitive/affective domains (Table 37) (p=0.388) (median Y1 2.86–Y2 2.86) indicate that the medians of the two samples are not significantly different from each other. At the beginning of the semester before undertaking any practical work, Year 1 undergraduates scored similarly to undergraduates completing the questionnaire at the end of the semester in Year 2, showing that expectations were high in Year 1 and remained high in Year 2.

Table 35

Year 1 pre-test and Year 2 post-test for the cognitive domain: Mann–Whitney U test



Ranks

	YearCognitiveY1preY2post	N	Mean Rank	Sum of Ranks
CognitiveY1preY2post	1	166	176.35	29274.00
	2	140	126.41	17697.00
	Total	306		

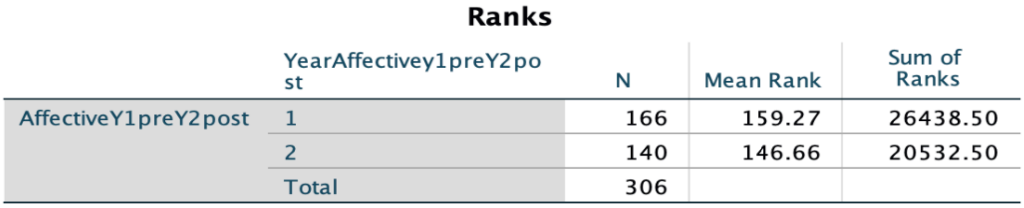
Test Statistics[a]

	CognitiveY1preY2post
Mann-Whitney U	7827.000
Wilcoxon W	17697.000
Z	-4.938
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: YearCognitiveY1preY2post

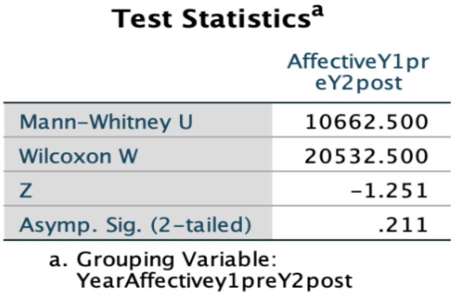
Table 36

Year 1 pre-test and Year 2 post-test for the Affective domain- Mann Whitney U test



Ranks

	YearAffectivey1preY2post	N	Mean Rank	Sum of Ranks
AffectiveY1preY2post	1	166	159.27	26438.50
	2	140	146.66	20532.50
	Total	306		



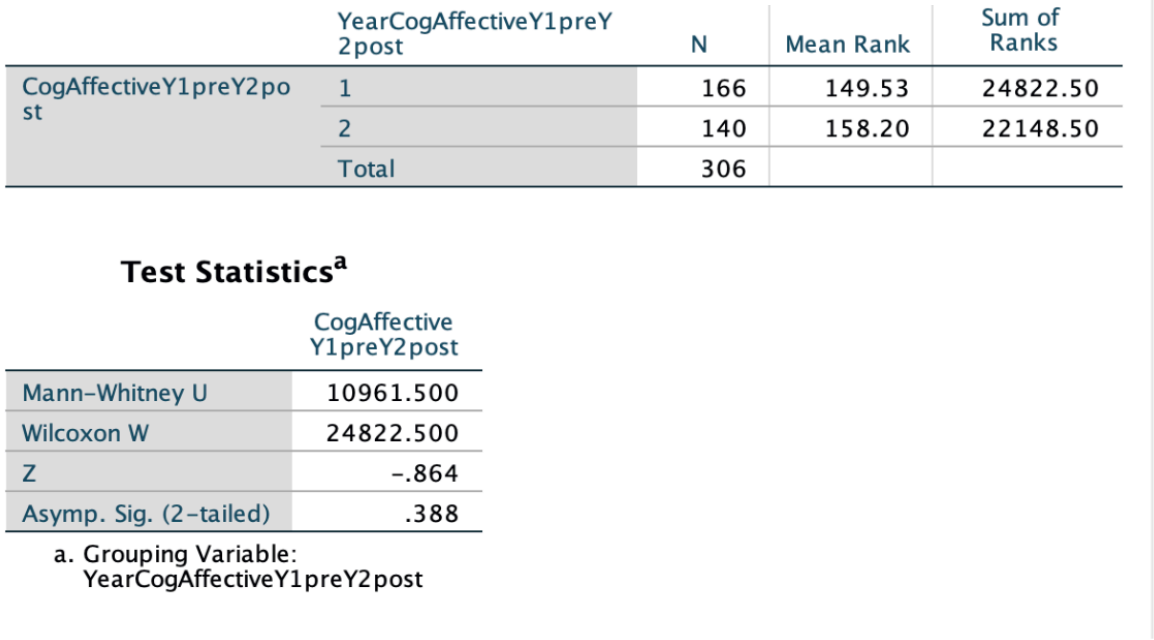
Test Statistics[a]

	AffectiveY1preY2post
Mann-Whitney U	10662.500
Wilcoxon W	20532.500
Z	-1.251
Asymp. Sig. (2-tailed)	.211

a. Grouping Variable: YearAffectivey1preY2post

Table 37

Year 1 pre-test and Year 2 post-test for the cognitive/affective domain: Mann–Whitney U test



	YearCogAffectiveY1preY2post	N	Mean Rank	Sum of Ranks
CogAffectiveY1preY2post	1	166	149.53	24822.50
	2	140	158.20	22148.50
	Total	306		

Test Statistics[a]

	CogAffective Y1preY2post
Mann-Whitney U	10961.500
Wilcoxon W	24822.500
Z	-.864
Asymp. Sig. (2-tailed)	.388

a. Grouping Variable: YearCogAffectiveY1preY2post

Effect Size

In addition to reporting on the possible difference between data, it is necessary to illustrate the importance of the difference – in other words, how substantially different the groups are. According to Gignac (2019), the measure of the effect size (Cohen's d) can be calculated by using the formula below (Gignac, 2019, p. 166):

$$d = Z * \sqrt{\frac{1}{N_1} + \frac{1}{N_2}}$$

Table 38

Cohen's d and effect size

	Cohen's d	**Effect Size**	**Statistical Significance**
PreY1Y2-Cognitive	-0.13	Trivial	No significant difference
PreY1Y2-Affective	-0.19	Trivial	No significant difference
PreY1Y2-Cog/Aff	-0.28	Small	Significantly different
PreY1PostY2-Cognitive	-0.57	Medium	Significantly different
PreY1PostY2-Affective	-0.14	Trivial	No significant difference
PreY1PostY2-Cog/Aff	0.099	Trivial	No significant difference

Based on Cohen's guidelines regarding the threshold for interpreting the effect size (1988, as cited in Gignac & Szodorai, 2016; Ellis, 2009), Cohen's d is regarded as trivial if smaller than 0.20, small if equal to or greater than 0.20, medium if equal to or greater than 0.50, and large if equal to or greater than 0.80. Table 38 shows that for values with no significant difference, the effect size is trivial/insignificant. For the difference between Year 1 and Year 2's pre-tests in the cognitive/affective domain, the effect is considered close to a small effect. In other words, Year 2 undergraduates scored on average 28% lower when questioned about their expectations for the coming semester spent doing practical work, in comparison to Year 1 undergraduates. This variance was accounted for by the independent variable, which in this case is 'year of undergraduates'. For the difference between Year 1 pre-tests and Year 2 post-tests, the effect in the cognitive domain is considered close to a medium effect. Again, Year 2 undergraduates scored on average 57% lower when questioned about their laboratory experiences in the cognitive domain while doing practical work, indicating that their expectations were not fulfilled, contrary to Year 1 undergraduates' expectations.

Year 2 pre-test Year 2 post-test

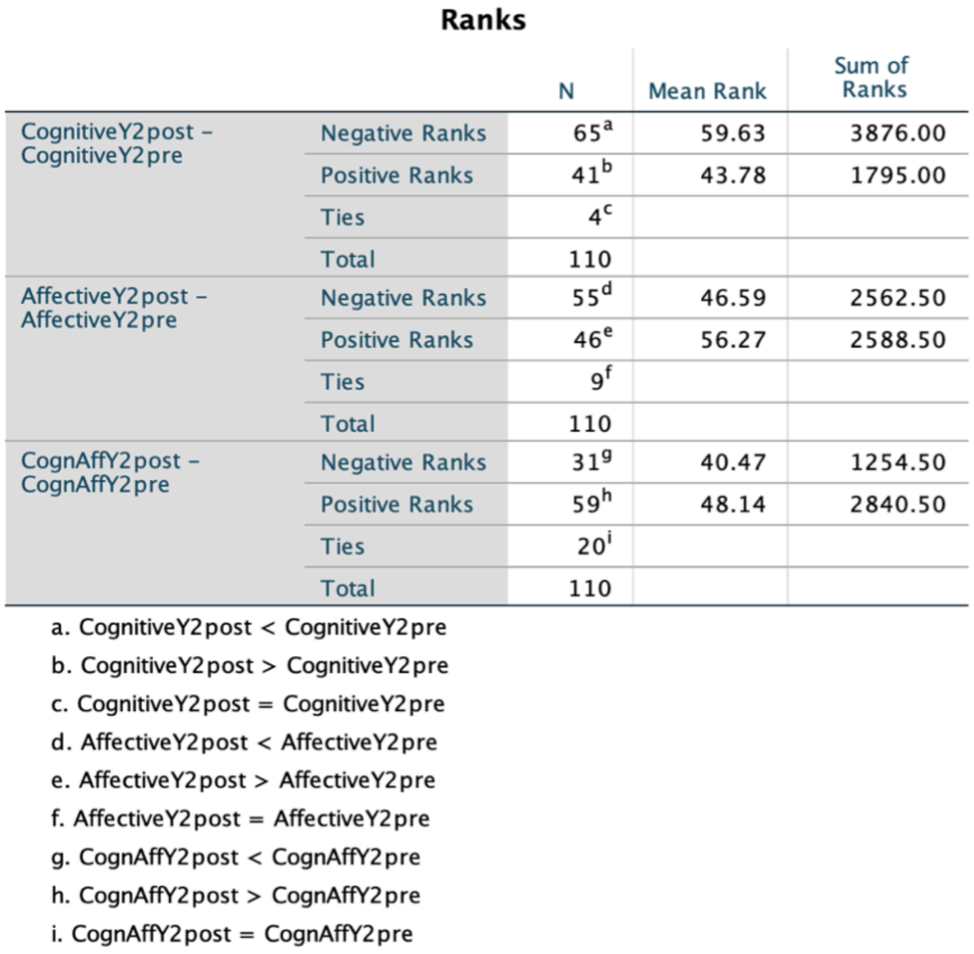
Ho: Year 2 students' experience, as reported in the pre-questionnaire, matches students' expectations in the post-questionnaire

For Year 2 pre- and post-tests, the Wilcoxon matched pairs test was used in order to calculate whether the medians of those two paired measurements are different from each other. The null hypothesis devised for this test is that there is no difference in the median pre- and post-tests, regarding expectations contributing to meaningful learning between the two semesters.

We can see from the table below (Table 39) that for the cognitive, affective and cognitive/affective domains, 65, 55 and 31 participants respectively had higher expectations at the beginning of the semester than at the end. However, 41, 46 and 59 participants respectively scored higher on their experiences at the end of the semester; this reflects satisfaction greater than their expectations, which were lower at the beginning of the semester. Examining the test statistics table, for the cognitive (p=0.001) and cognitive/affective domain (p=0.001), the null hypothesis is rejected, as we can say that the median difference is significantly different from zero. In fact, the median score for the post-tests for the cognitive domain (2.82) in comparison to the pre-test (2.94) is lower, reflecting higher initial expectations at the beginning of the semester which were not met at the end, based on the undergraduates' experience in the laboratory. In contrast, the median score of the post-test for the cognitive/affective domain (2.86) was higher than for the pre-test (2.71), indicating that undergraduates' experience was above their initial expectations. As for the affective domain (p=0.965), there is no evidence to reject the null hypothesis, as the median difference (2.63 for both pre- and post-tests) is not significantly different from zero. Undergraduates scored similarly on pre- and post-tests.

Table 39

Wilcoxon matched pairs test for Year 2 pre- and post-tests.



Ranks

		N	Mean Rank	Sum of Ranks
CognitiveY2post – CognitiveY2pre	Negative Ranks	65[a]	59.63	3876.00
	Positive Ranks	41[b]	43.78	1795.00
	Ties	4[c]		
	Total	110		
AffectiveY2post – AffectiveY2pre	Negative Ranks	55[d]	46.59	2562.50
	Positive Ranks	46[e]	56.27	2588.50
	Ties	9[f]		
	Total	110		
CognAffY2post – CognAffY2pre	Negative Ranks	31[g]	40.47	1254.50
	Positive Ranks	59[h]	48.14	2840.50
	Ties	20[i]		
	Total	110		

a. CognitiveY2post < CognitiveY2pre

b. CognitiveY2post > CognitiveY2pre

c. CognitiveY2post = CognitiveY2pre

d. AffectiveY2post < AffectiveY2pre

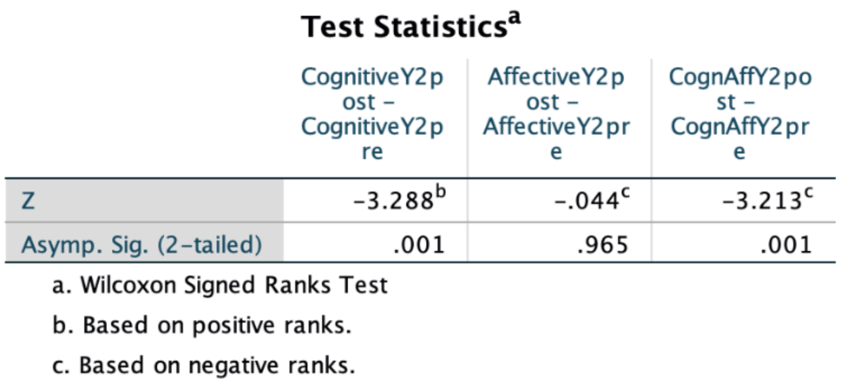
e. AffectiveY2post > AffectiveY2pre

f. AffectiveY2post = AffectiveY2pre

g. CognAffY2post < CognAffY2pre

h. CognAffY2post > CognAffY2pre

i. CognAffY2post = CognAffY2pre



Test Statistics[a]

	CognitiveY2post – CognitiveY2pre	AffectiveY2post – AffectiveY2pre	CognAffY2post – CognAffY2pre
Z	-3.288[b]	-.044[c]	-3.213[c]
Asymp. Sig. (2-tailed)	.001	.965	.001

a. Wilcoxon Signed Ranks Test

b. Based on positive ranks.

c. Based on negative ranks.

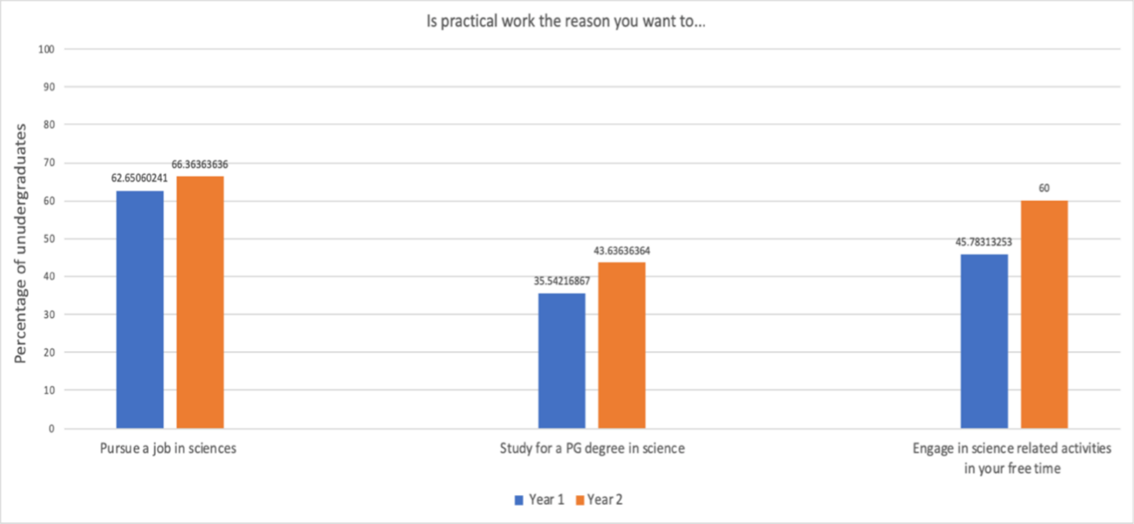
To summarise, the data indicate that Year 1 undergraduates' expectations in the cognitive and affective domain at the beginning of the semester and upon arrival at the university, regarding what they would do in the laboratory, were not significantly different from expectations of Year 2 undergraduates. For the cognitive/affective domain, Year 1 undergraduates had higher expectations than Year 2 undergraduates, who already had one year of experience in the laboratory. In terms of the cognitive domain, expectations were much higher at the beginning of the semester for Year 1 undergraduates, in comparison to Year 2 undergraduates, whose experience after one semester in their second year of studies did not meet their initial expectations. Moreover, the affective and cognitive/affective domains had high scores both in pre- and post-tests, indicating that experiences met their expectations. Lastly, for Year 2 undergraduates, initial expectations at the beginning of the semester were higher than those found in the laboratory for the cognitive domain. The cognitive/affective domain showed that their experiences were above their initial expectations, whereas for the affective domain, there was no difference between before and after. Overall, all undergraduates in Years 1 and 2 gave high scores in the questionnaire, despite the statistical differences presented, with a mean score of 2.79 on the Likert scale indicating a positive belief regarding meaningful learning.

"Is practical work the reason you want to [...]?"

Undergraduates in both Year 1 and Year 2 were also invited to explain whether practical work made them want to pursue a science career, further their studies in science, and engage in science-related activities in their free time. As can be observed from Figure 20, Year 2 undergraduates were overall more interested in engaging with extracurricular science-related activities in their free time, and more of the half of the class (66.4%) wanted to pursue a job in sciences. However, the interest in pursuing a postgraduate degree in science for both Year 1 and Year 2, despite the higher percentage in the latter, was low. Finally, 60% of Year 2 undergraduates showed that practical work was the reason they wanted to engage in science-related activities in their free time, contrasting with 46% of positive responses from Year 1 undergraduates.

Figure 20

"Is practical work the reason you want to …?" Percentage of undergraduates' responses in Year 1 and Year2



Meaningful Learning Questionnaire: Investigating Affective Experiences

In order to achieve Meaningful Learning, undergraduates should integrate cognitive and affective learning with the psychomotor. Questions were categorised based on their connotations regarding feelings; positive (Q2, 3, 5, 8, 11, 13, 15, 17, 19, 20, 27, 28) and negative (Q4, 7, 12, 16, 25, 26, 29, 32). Findings include the comparison of positive and negative questions for each year, the comparison of the two 'Feelings' categories between questionnaires administered at the beginning of the semester for Year 1 and Year 2, questionnaires administered at the beginning of Year 1 and end of semester for Year 2, as well as questionnaires administered at the beginning and end of Year 2. Negatively keyed items (Q2, 3, 5, 8, 11, 13, 15, 17, 18, 19, 20, 27, 28 in Table 31) were reversed-coded so that a high score would indicate a positive opinion of meaningful learning. For this reason, low scores in the 'Negative Feelings' category indicate negative views of undergraduates' experience in the laboratory. Comparisons between questions for each year aimed to investigate consistency between answers to questions with negative and positive connotated wording (e.g. "I am anxious, confused, frustrated, nervous"; "I am confident, excited, I persevere"). Moreover, a comparison of questionnaires across semesters and years aimed to investigate which type of feelings dominated: positive or negative.

Table 40

Questionnaire comparisons from data collected at the beginning of the semester for each year (Pre-) and at the end of the semester (Post-) to assess meaningful learning

Year 1 Pre-test	**Year 2 Pre-test**	**Difference 12 months**
Year 1 Pre-test	**Year 2 Post-test**	**Difference 16 months**
Year 2 Pre-test	**Year 2 Post-test**	**Difference 4 months**

Meaningful Learning Questionnaire: Investigating Engagement with Ideas

As observed in Figure 21, undergraduates in both Year 1 and Year 2 pre- and post- their experiences in the laboratory scored a median of 3 on the Likert scale (3: Agree), indicating that they did not have any negative feelings about their expectations of and experience with practical work.

Specifically, the median score indicates that undergraduates did not think they would be, and they were not:

Worried about finishing on time

Confused about how instruments work

Unsure about the purpose of procedures

Nervous about making mistakes

Feeling disorganised

Worried about getting good data

Confused about underlying concepts

Nervous when handling chemicals/samples

Worried about the quality of their data

Frustrated

Intimidated

Confused about wat their data meant.

Instead, undergraduates' median score from the questionnaires indicated that they expected, and they indeed:

Experienced moments of insight

Were excited to do science

Developed confidence in the laboratory

Got stuck but kept trying

Made mistakes and tried again

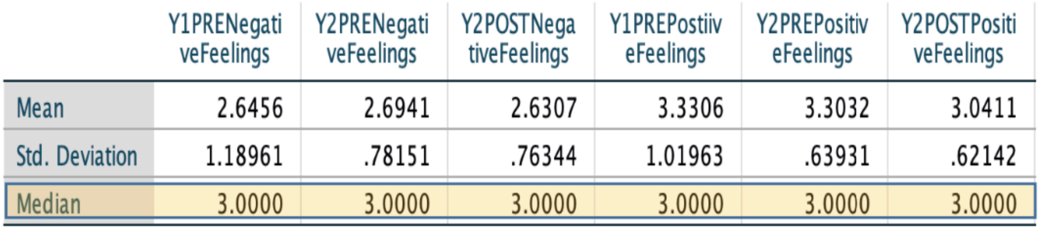
Were intrigued by instruments

Were confident when using equipment

Gained practical work experience for future jobs

Overall, their responses to questions whose wording was contrasting (e.g. "I am anxious, confused, frustrated, nervous"; "I am confident, excited, I persevere") was consistent and did not indicate any contradicting statements.

Figure 21
Comparison of affective categories across years and/or semester



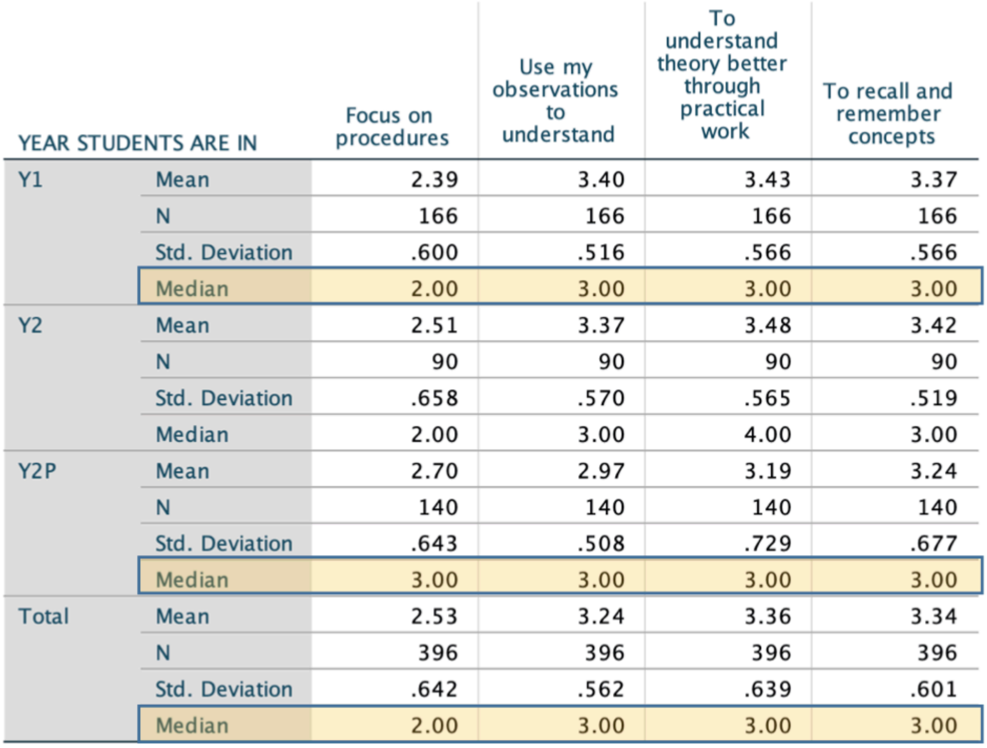
	Y1PRENegativeFeelings	Y2PRENegativeFeelings	Y2POSTNegativeFeelings	Y1PREPostiiveFeelings	Y2PREPositiveFeelings	Y2POSTPositiveFeelings
Mean	2.6456	2.6941	2.6307	3.3306	3.3032	3.0411
Std. Deviation	1.18961	.78151	.76344	1.01963	.63931	.62142
Median	3.0000	3.0000	3.0000	3.0000	3.0000	3.0000

Meaningful Learning Questionnaire: Investigating the Use of Ideas during Practical Work

Lastly, questions concerning the use of scientific conceptual ideas during practical work were investigated separately and as a whole, so as to understand whether undergraduates were 'minds-on' during their experiments. According to undergraduates' answers in the questionnaire, in Year 1 they were not expecting to focus on procedures instead of concepts during their upcoming practical work lessons (2: Disagree). After one year of experiencing practical work in the laboratory, Year 2 undergraduates, again, did expect to focus on procedures instead of concepts (2: Disagree). After one semester of practical work for undergraduates in Year 2, they reported that in the end they did focus on procedures and not on concepts (3: Agree). Before starting practical work lessons, both Year 1 and Year 2 undergraduates expected to use their observations to understand the behaviour of humans/animals/plants/cells/atoms and molecules (3: Agree). Year 2 undergraduates reported that after one semester of practical work they did indeed use their observations for further understanding the organisms or molecules they were observing (3: Agree). All undergraduates both in Years 1 and 2 agreed that they understood theory better through practical work, even though Year 2 undergraduates seemed to be more confident in their expectations about their conceptual understanding (4: Strongly agree) in comparison to their answers at the end of the semester (3: Agree). Lastly, all undergraduates confirmed that their expectations were met, and they were indeed able to recall and remember concepts because of practical work (3: Agree).

Figure 22

Comparison of questions indicating the use of scientific ideas during practical work



YEAR STUDENTS ARE IN		Focus on procedures	Use my observations to understand	To understand theory better through practical work	To recall and remember concepts
Y1	Mean	2.39	3.40	3.43	3.37
	N	166	166	166	166
	Std. Deviation	.600	.516	.566	.566
	Median	2.00	3.00	3.00	3.00
Y2	Mean	2.51	3.37	3.48	3.42
	N	90	90	90	90
	Std. Deviation	.658	.570	.565	.519
	Median	2.00	3.00	4.00	3.00
Y2P	Mean	2.70	2.97	3.19	3.24
	N	140	140	140	140
	Std. Deviation	.643	.508	.729	.677
	Median	3.00	3.00	3.00	3.00
Total	Mean	2.53	3.24	3.36	3.34
	N	396	396	396	396
	Std. Deviation	.642	.562	.639	.601
	Median	2.00	3.00	3.00	3.00

Data Analysis F: Interviews with Undergraduates

Findings from Section F and E will be presented in an attempt to answer Research Question 3: [According to undergraduates' interviews] Does practical work contribute towards meaningful learning? If so, to what extend does the affective value contribute to that learning?

This section presents findings acquired from brief on-the-spot interviews with Year 1 and Year 2 undergraduates while doing practical work in the laboratory. Main themes are identified after thematically analysed, along with a discussion of the outlined research findings. The discussion was open-ended and undergraduates were asked about their experience in the lab while doing practical work, what they liked about it and what challenges they faced. Although the interviews were short, a pattern of common themes arose during discussions with the undergraduates; these are summarised below.

After the interview analysis, four main thematic categories were identified, summarising undergraduates' experience in the laboratory. Themes were related to the role of members of staff, assessment of their work, the value of pre-learning, as well as their personal opinion about practical work, with two subthemes of liking and disliking the activities. These themes are presented and discussed further below, including excerpts from the interviews.

Theme 1: The Role of Members of Staff

One important theme emerging from the interviews was the staff members' role and how their guidance affected and helped to improve undergraduates' experience in the laboratory while doing practical work.

> *The demonstrators walk around knowing how to explain everything, so as to help us go from point A to point B and finish our task. They confirm whether our findings are correct or wrong, and help us develop our skills year by year.*
>
> Student 1

Indeed, demonstrators' role in the laboratory was to move around, make sure everything was running smoothly, and to directly interact with undergraduates on a one-to-one basis, in order to remind them of theories linked to what they were doing and looking at. As the demonstrators mentioned,

> *It is like an apprentice learning from a more knowledgeable other. We teach students what they need to know.*
>
> Staff 1

Their valuable help is confirmed by undergraduates in the following conversations:

> *Demonstrators make us feel confident. It is good when you know what you are doing, and demonstrators help us get rid of that worry. We get an idea from our lecturer on what we need to do and then we work things out with them. It is important to watch someone expert teaching you how to do it, so you can become an expert yourself slowly.*
>
> Student 2

> *It is important to watch someone expert teaching you how to do it, so you can become an expert slowly.*
>
> Student 3

> *When you do things yourself you make your own knowledge and you see things you could not be able to see in books, as long as the demonstrators help with the theory you need to know.*
>
> Student 4

> *Some teachers leave us alone to do guesswork. We like having support. It is good that the lecturer points out things to you so you can know what you should look for.*
>
> Student 5

> *Demonstrators are our scaffolds, if you like. They provide us with the knowledge needed so as to put all the puzzle pieces together.*
>
> Student 6

Theme 2: Assessment

The majority of undergraduates seemed to be concerned about whether their work was being assessed, to estimate the effort they had put into their practical activity in the lab. It was evident from the beginning of the practical work lesson that undergraduates were interested to know how much the practical activity contributed to their overall grade and whether it would be formally assessed. Some expressed their opinions openly:

> *If [the practical activity] is assessed I will put the effort to take notes and try to remember what I did. If not I will probably forget, because I will not put too much effort into trying to understand the theories behind the activity and how I can link everything. This is because I will not have to write anything up.*
>
> Student 7

It was obvious upon entering the laboratory that undergraduates were chatting and being distracted by their conversations. As soon as members of staff mentioned that the activity was going to be assessed, there was silence, and everyone began paying attention while taking notes.

> *If it is assessed you have to read everything in the guidebook and protocol word by word to take it in. We prefer relaxed sessions to be able to digest material.*
>
> Student 8

However, the aforementioned statement did not reflect reality, as undergraduates did not seem to put much effort into non-assessed activities.

> *If it is not assessed, we do not care much. You can also see that people are not attending when we are not required to submit anything, so now that they want us to write reports or take quizzes for everything, the attendance rate went up. People are more engaged, there are more questions.*
>
> Student 9

Theme 3: Approaches to Learning when Doing Practical Work

Pre-Learning

As observed in previous parts of this chapter, on most occasions the majority of undergraduates lacked understanding of the main theories and could not recall them. As a result, it was interesting to ask the group of undergraduates who could answer questions correctly and demonstrated an ability to combine observables with theories, how they achieved that. This took place while observing a plant anatomy lecture:

> *I think I can identify cells, with most of these I am finding I know the regions rather than the actual cells… I can see the secondary and primary xylem. I had to revise before coming to the practical because this helps to reinforce the theory. I enjoy it a lot when I come prepared.*
>
> Student 10

> *Xylem is responsible for water transport. It is darker stained because it is lignified. It supports the plant. I always study before coming to a practical. Not knowing the theory does not help when you need to reach conclusions and understanding. We just need to do it. We need to read beforehand.*
>
> Student 11

Regarding undergraduates who could not answer subject-related questions, it was interesting to see what their approach was. Most of them responded in a very similar way:

> *Practical work sometimes is not effective in helping you know the theory on the spot. We end up asking questions for clarification but we have to go and read everything later to make sense. Theory is great but it's just theory, and without the experiment we cannot combine the two.*
>
> Student 12

> *I have no idea what I am looking at but I usually see things, and then I will have to read about them to make sense.*
>
> Student 13

> *You see, you go home, you recall. You refresh things.*
>
> Student 14

Theme 4: Personal Opinions on Practical Work

While observing practical work in the laboratory, it was recognised that most undergraduates were excited and enthused about being there. Their approach directly influenced the atmosphere in the laboratory, along with the undergraduates' collaboration with members of staff, to allow the laboratory lesson to run smoothly and effectively. Although responses varied based on the reasons behind undergraduates' preference for practical work, the main sub-themes included the capacity of practical work to help them "visualise" things, remember, and progress in their careers.
The most common answers included comments related to the subthemes below:

Career-related

Being in a lab is our job. I want to work in a hospital.

Student 15

… I like labs. I am a scientist.

Student 16

If you realise that you want to work in science, you enjoy practicals because they help you.

Student 17

This is better than sitting in a lecture. We will probably need to repeat these procedures in the future, but it's good to get introduced to important things that we will have to use in a laboratory in the future.

Student 18

Last year we got started with cheap equipment. Now we see the actual industrial stuff. Practical work consolidates your learning. They will never give you hands-on experience to go to the industry unless you do a practical.

Student 19

The more practicals we do the more confident we are in our subject. This lab helps us experience new things and learn fundamental skills for the future.

Student 20

Every practical gives us transferable skills for later on.

Student 21

Structure of the Lesson

Some of the comments were directly related to the way members of staff designed the practical activity that directly affected undergraduates' experience in the laboratory.

It's fun and we like it [practical work] because when everything is properly structured we can get enough information from the guidebook and then from members of staff, along with detailed steps on what to do and what to see.

Student 22

It helps me understand what I am seeing. It also helps to be given guidebooks with diagrams because it is easy to remember after you do it in the lab because you put more work into it, rather than just looking at a diagram in the book. Practical work is beneficial for me as I understand what I am learning.

Student 23

When the practical is too long and I have to read and do a lot of things, I end up confused.

Student 24

Some practicals are too long when you have so many things to do, I get bored.

Student 25

If you asked me a question after a lecture I would remember, but when a practical happens before a lecture, it does not work for me

Student 26

Visualise

One of the main advantages of practical work for undergraduates was that they could combine lectures with experiments in order to see in real life what they saw in books.

> *We like practical work in general, it is fun and we are working with living organisms. It's interesting to see things in real life.*
>
> Student 27

> *Lectures help us to learn theory, practicals help in learning the process. For example I learned that staining has to do with cell walls, but I know that from a lecture, now I have the chance to visualise it and see things myself.*
>
> Student 28

> *It helps us getting familiar with theories. For instance, we were told about the behaviour of an insect but now we can see that behaviour in real life.*
>
> Student 29

Remember

In discussing the reasons why practical work was advantageous for undergraduates, the word "remember" was frequently brought up in conversations, as practical work was regarded as a medium for learning.

> *I see things, I interact and I remember. I take notes and when I go home I read relevant theory and tie things up.*
>
> Student 31

> *You remember things when you get involved. We worked on some techniques last year and now everything has started to stick.*
>
> Student 31

> *When you interact you kind of remember things because you touched something. It's tangible.*
>
> Student 32

> *Hands-on helps you remember. It helps you see what you are reading. Everything ties up with lectures.*

Student 33

> *When you invest time during the activity and you engage with everything around you, it gives you the chance to think. Then everything automatically stays in your mind.*

Student 34

> *This reinforces theory, especially if you are a visual person you can see theory in front of you.*

Student 35

Lastly, in some circumstances it was clear that a minority of undergraduates found practical work not useful at all.

> *I hate practicals because information is all gone when I leave. I forget everything.*

Student 35

> *Hope this practical will not last long, as I need to go home and do some real work. I will not remember anything once I get out of this door.*

Student 36

Chapter 5 Discussion

Introduction

As Millar (1987) aptly questioned, after years of debate regarding the purpose of practical work in education:

> *"But what is this practical work for, and what learning does it promote? Its very taken-for-grantedness means that this question is often not asked […] We reply simply that "science is a practical subject" and leave it at that. '*
>
> *(p. 113, as cited in Abrahams, 2011)*

Urena and Gatlin (2012) highlighted the need for high-quality research that will increase the understanding of the purpose of practical work and laboratory instruction. Tertiary institutions continue investing financial resources in an "act of faith" (Urena & Gatlin, p. 142) that practical work activities will eventually lead to improvement in conceptual learning, not taking into consideration such variables as the implementation and impact of the affective value in learning. Hodson (2005) clarified that criticism of laboratory instruction should not be regarded as an attack on practical work per se, but rather as constructive criticism of the kind of practical work being conducted in undergraduate teaching laboratories, and how it is being implemented in learning.

Having presented findings from laboratory observations, as well as undergraduate and staff member interviews and questionnaires in the previous chapter, this chapter aims to review the conclusions derived from the data analysis by addressing the three core research questions listed below, exploring them through relevant theoretical frameworks and linking them with existing literature. Additionally, emerging key themes are identified and discussed, and suggestions based on this study's findings will be made. A learning model that indicates the potential for successful learning in the laboratory is proposed within the framework of constructivism – a topic that can be explored and addressed in further research, as discussed in Chapter 6.

Throughout the chapter, the term 'students' refers to learners in secondary education whereas 'undergraduates' refers to learners in tertiary education.

Research Questions

1. What are the aims of practical work amongst a small representative sample of lecturers in the department of life sciences at the chosen university?
2. Are practical tasks effective in enabling undergraduates do or/and learn what is intended?
    a. If yes, when?
3. Does practical work contribute towards meaningful learning?
    a. If so, to what extent does the affective value contribute to that meaningful learning, and what is it for?

Research Question 1

What are the aims of practical work amongst a small representative sample of lecturers in the department of life sciences at the chosen university?

Lecturers' Activity (Kerr's Aims) and Observed Practical Work Lesson Structure

The first research question addressed by this study concerned the perceived aims of practical work in the department of life sciences, according to a small representative sample of lecturers at the chosen university. The approach taken in order to answer this research question was to analyse responses acquired from an adapted version of Kerr's (1963) activity, in which 14 members of staff were requested to rank 10 aims of practical work in order of importance for Years 1–3. It was decided that this question should be addressed first so as to set the foundations for this study, as in order to question the effectiveness of practical work, it is important to know the standards against which this 'effectiveness' is measured. As Millar (2009) explains, the lesson developer's view of science, influences the way it is designed. As a result, the aims of practical work contribute in understanding what members of staff prioritise. Academic staff, either intentionally (pre-planned) or unintentionally, determine the aims upon which their laboratory lessons will focus through the activities that they introduce in class when designing a curriculum (George-Williams, 2018). The teaching approaches used to deliver activities depend upon – and at the same time, determine – the aims that will underlie practical work lessons (Seery et al., 2018).

As mentioned in the literature, a broad variety of practical work aims have been suggested over the years, leading to confusion surrounding the misalignment of lesson purposes and students' expectations (Seery, 2020; Santos-Diaz et al., 2019; DeKorver & Towns, 2015) similar to what was found in this current study. Undeniably, having a long list of proposed goals, as several reports have shown (Boud et al., 1980; Reid & Shah, 2007; Bruck et al., 2010; Bretz et al., 2013, 2016; George- Williams et al., 2018, QAA,2019) makes it difficult to reach a consensus between faculty members regarding the purpose of practical work in a curriculum and suggested best practices, as these can differ depending on teaching staff and modules (Seery, 2020; National Research Council, 2006).

From the findings presented in this study (Figure 18, Ch.4), it has become evident that there is a gradual progressive training plan for undergraduates to follow from Year 1 to Year 3, corroborating findings from Biggs (2012) stating that it is expected from undergraduates at university level to learn to work autonomously and make decisions on their own, something valued and expected in their forthcoming professional career. Year 1 focuses on helping them to develop abilities such as adopting simple scientific methods of thought, making physical phenomena more real through actual experience and developing manipulative skills. In Year 2, training in problem solving is prioritised, and the application of scientific methods of thought is downgraded, because undergraduates by this time should be more comfortable with this approach. Encouragement of accurate observation and careful recording becomes the third most important aim and remains in the same ranking position for Year 3. The first and third aims observed in Year 2 remain the same for Year 3, and an aim which was seen to be amongst the three least important, i.e. finding facts by investigation and arriving at principles, is now ranked second.

This gradual progression of skill acquisition in the teaching of Life Sciences aligns with Lott's (2011) and Seery et al.'s (2018) curriculum model for developing experimental design, as each year is progressively more difficult until undergraduates are comfortable and skilled enough to undertake an unfamiliar research experiment, such as the final-year individual research project, which in the UK takes place in Year 3. Comparing these findings with those presented by Kerr (1963) and Thompson (1975), although referring to students in secondary education, accurate observation was highly encouraged and was ranked amongst the top aims in both studies (Woolnough, 1976). Abrahams and Saglam (2010) found that the encouragement of accurate observation becomes less important as students progress to senior years, if this aim has been effectively followed and met in earlier key stages; however, findings from this current study demonstrate that some aims, including accurate observation, are prioritised and maintained throughout the three undergraduate years. These aims also align with the broad expectations and criteria for academic standards in Biosciences within UK Higher Education as identified by the QAA (QAA, 2019). Evidently, the most important aims for Year 1, including "To promote simple common-sense scientific methods of thought" and "To develop manipulative skills" are becoming less significant as undergraduates progress to more senior years; whilst the least important aims for Year 1, which require advanced thinking and dexterity – including "To give training in problem solving " and "To be an integral part of the process of finding facts by investigation and arriving at principles" – are prioritised, amongst the top three.

These findings are further supported by published literature, explaining that laboratory instruction approaches (Domin, 1999) initially follow the expository model, which is at the bottom of the enquiry rank (Level 0) due to its minimal knowledge-demanding nature (Fay et al., 2007); then there is a progressive transition, as undergraduates acquire the fundamentals of relevant subject-related knowledge and learning of skills and competency (Seery et al., 2018), towards open-enquiry teaching models, which are best represented by the final-year research project of science students (Johnstone & Al-Shuaili, 2001). In Year 2, as undergraduates gain confidence and competency, they are introduced to higher-order thinking skills such as predicting and explaining; this transforms a recipe-like practical work lesson into a more advanced form that fits higher levels of enquiry (Level 1+) (Fay et al., 2007). The findings reflect and match those observed in previous studies conducted in secondary education: for instance, according to Sharpe (2012), lower years were focused on learning scientific methods, whilst for more senior years the development of skills such as observing, recording and investigating were prominent (Hodson, 1993). Moreover, the purposes of practical work in university life sciences education share similarities with those in secondary education, with the latter providing a foundation for the former to promote advanced higher order cognitive thinking and skill development. This way the university programs offer a gradual and transitional route towards advancing cognitively and skill-wise. Although enhancing motivation is not one of the goals of university life sciences, undergraduates are nonetheless required to work more autonomously in order to be independent and gain decision-making skills. Practical work in university should ideally, based on literature, combine theory and practice, building on prior theoretical learning. This way undergraduates who work in laboratories learn how to incorporate scientific approaches into their daily lives and develop professional attitudes (Brown & Atkins, 1988; Kirschner & Meester, 1988; Trumper, 2003; Khoon, 2004; Wang, 2005; Biggs, 2013; Boud et al.,1980, Brewer et al.,2014). In terms of the perceived aims of practical work, in this study Year 2 was regarded as a transitional year, combining aims from both Year 1 and Year 3 in order to further develop pre-taught skills – as well as introducing more advanced ones required to progress further, which will be applied in the final year.

Results obtained from Kerr's (1963) activity were later compared to the themes identified from lecturers' interviews, as their responses related to the main aims of practical work are aligned with the prioritisation of Kerr's aims in the activity. It is evident that practical work was regarded as a hands-on activity which allows undergraduates to be trained for a future career in the sciences, by developing their skills and becoming independent in the laboratory. Although the development of manipulative skills is prioritised in Year 1 and becomes less important as undergraduates progress to senior years, this does not signify that undergraduates are no longer working on the maintenance and advancement of those skills. In fact, it is apparent from the laboratory observation results, that in eight out of nine and in seven out of nine laboratory lessons for Year 1 and Year 2 respectively, the intended learning objective was to learn how to use a piece of equipment or follow a standard practical procedure. From the data, the prioritisation of developing skills is demonstrated by the fact that in the learning objectives of laboratory lessons for Year 1 in seven out of nine lessons, undergraduates were expected to be trained in using equipment and following practical procedures that they had not previously faced.

Transitioning to Year 2, only four out of nine times were undergraduates introduced to unfamiliar techniques and equipment, as in seven out of the nine laboratory lessons observed, Year 2 undergraduates had to work with methodological approaches that had been previously used . For Year 2 undergraduates, scientific enquiry becomes more demanding as its advanced aspects are introduced, such as planning methodological approaches, choosing equipment, and identifying a research question. However, these aspects were not commonly seen in the practical work lessons observed, as they better reflect open-enquiry practical work models which are seen in Year 3 individual research projects. Nonetheless, aspects of scientific enquiry such as analysing and presenting data, drawing evidence-based conclusions, and assessing the validity of conclusions were introduced and assessed in laboratory reports.

These findings align with Bruck and Towns's (2013) study where faculty members placed a higher priority on laboratory procedures early in the degree and placed more emphasis on error analysis, data gathering and analysis towards the final years of their degree. Additionally, the design of practical work lessons addresses the call for an urgent demand for scientists with skills made by the UK's Department of Innovation and Skills (Smith,2017) and meets the proposed alterations suggested by Woodin Carter and Fletcher (2010) for an undergraduate program offering undergraduates the opportunity to develop their competencies, skills, understanding of scientific processes and its applications. Additionally, the Royal Society of Biology supports high-quality practical work as a means of fostering problem-solving, observation, measurement and analysis.

Moreover, in this study, laboratory observations attempted to review laboratory instruction types and relate them to the aims attested by members of staff. As previously mentioned, laboratory instructions have been observed to be either expository-, inquiry, discovery- or problem-based (Johnstone & Al-Shuaili, 2001). As Domin (1999) explained,these styles can be differentiated by their outcome, approach and procedure. In all of the 18 practical work lessons observed for both Year 1 and Year 2, the activities were designed by members of staff, the procedure was given, and detailed instructions on the procedure were provided to undergraduates, along with class discussion on ideas and relevant theories, in four and five Year 1 and Year 2 lessons respectively. Although the outcome was predetermined by members of staff, it was unknown to undergraduates, who were asked to compare their results against the expected outcome at the end of the lesson; in seven and six out of nine times in Year 1 and Year 2, respectively, class discussion was encouraged with regard to confirming what they had seen. For Year 2, in seven out of nine observed practical work lessons, explanation as to how observations are related to conceptual ideas was carried out. This, however, conflicts with the aforementioned aims determined by members of staff, as the elucidation of theoretical work through practical work for increased comprehension was found to be amongst the bottom three aims of practical work for both Year 1 and Year 2, phenomenally overlooking the need for undergraduates graduating with adequate scientific knowledge as requested by the Department of Innovation and Skills (Smith,2017), but potentially suggesting that knowledge acquisition is not a direct result of practical work *per se (*Hirvonen and Viiri, 2002).

In Year 2, seven out of nine practical work lessons required undergraduates to suggest possible explanations for data; however, the average rating on importance of scientific ideas for successfully completing practical tasks in the laboratory, for all nine classes in Year 1 and

Year 2 respectively, was below 3. The averages were coded as ‘unimportant’ and ‘not very important’, following Millar’s observation instrument (2009); this contrasts, once again, with the aims set by members of staff, as the elucidation of theoretical work through practical work was ranked amongst the least important aims, behind the rationale for undertaking practical work. However, it is interesting that the logical structure of the practical task in five and six practical work lessons in Year 1 and Year 2 respectively, required undergraduates to collect data on a situation and think about how it might be explained at a later stage, which indicates that theoretical knowledge acquisition can happen after a practical work activity. Even though undergraduates required minimal conceptual knowledge to complete experiments, the exact conceptual knowledge missing was communicated to them by members of staff throughout the experiments. In only three Year 2 practical work lessons were undergraduates required to use theoretical knowledge prior to an experiment, in order to set a hypothesis to test. Generally, the learning demand for both Year 1 and Year 2 practical tasks was moderate, allowing undergraduates to perform experiments from start to finish; even if they lacked the necessary theoretical background to explain, during an experiment, why they were doing those tasks, and how findings could be linked to ideas and theories. Indeed, of the nine laboratory classes observed for each year, only in four Year 1 and five Year 2 practical work lessons did members of staff discuss ideas and theoretical concepts prior to an experiment, as the importance of scientific ideas for carrying out the activity well ranged from unimportant to not very important for both Year 1 and Year 2.

Although the elucidation of theoretical knowledge is not one of the reasons for conducting practical work lessons, according to the aforementioned preferred aims ranked by members of staff, nevertheless it is implicitly a required skill – based on the fact that Year 2 undergraduates are assessed on a report in which they need to explain their observations by means of underlying theories and models. Even in this case, when interviewed, members of staff explained that assessment is mainly used for attendance purposes or as an incentive for undergraduates to focus during experiments, to merely produce good results. Concerning theoretical knowledge, some members of staff explained that laboratory reports help them to see whether undergraduates understand underlying theories regarding an experiment, whilst ensuring that they provide support and discuss findings at the end of the lesson. At this point, findings indicate that the elucidation of theoretical knowledge as a result of practical work is not regarded as a priority by members of staff, based on their perceived aims; this contrasts with the results of George-Williams et al. (2013), wherein 30% of academic staff raised theoretical understanding as an important theme among the aims of practical work.

Practical work alone might not be the primary reason behind the understanding of theoretical knowledge, as undergraduates, based on observations, are not required to have a theoretical background for the completion of an activity. However, aims such as "making physical phenomena more real through experience" and "training in problem solving" give undergraduates the opportunity to understand material upon completion of their practical work lessons (rather than during experiments). As Kirschner (1992) argues, learning about sciences is best done by being taught how to do it, rather by actually doing it.

Lecturers' Activity (Kerr's aims) and Personal Interviews

When lecturer interviews were conducted, to provide further clarity and deeper discussion on the aims of practical work, it was evident that staff all shared similar perceptions and beliefs. The findings revealed that practical work was regarded as a training medium in which undergraduates gain hands-on experience that allows them to develop the skills required to pursue a career in the sciences, and work independently and confidently. Although the results presented in George-Williams et al. (2018) indicate that whilst the enhancement of laboratory skills and equipment usage was rated as an important aim of practical work at university (by 67% of members of staff), which aligns with the faculty goals in Bretz (2013), only 6% believed that it should prepare students for their future careers in industry or research (even though the acquisition of skills does not negate the possibility of their application in industry). On the contrary, present findings from this study in biosciences seem to be consistent with literature on the history of practical work in other science disciplines, which explains that it was introduced at universities to train technicians and industry workers with the skills required to contribute to industry (Seery, 2020; Elliot et al., 2008; Reid & Shah, 2007). Additionally, lecturers' aims for life science graduates seem to be in accordance with the UK's Department of Innovation and Skills vision, which highlights a high demand for scientists with good knowledge and a good skillset within their field (Smith, 2017).

Importantly, all of the lecturers highlighted that one of the most important aims of practical work is related to undergraduates' future career, and how they are benefited by developing skills and acquiring practical work experience. Lecturers felt responsible for the new generation of scientists and their laboratory training, so that they can contribute to society. Furthermore, lecturers added that by providing undergraduates with multiple, albeit short-spanned, opportunities to become accustomed with equipment and procedures, they can not only gain insights into the chosen specialism for their future career, but also be prepared for job interviews, as they would be able to discuss various laboratory experiences with future employers. Based on the findings from interviews with undergraduates in the department of life sciences, one of the most important reasons for preferring practical work was career-related aspirations as equipment, procedures, and hands-on experience in general equipped them with transferable skills for the future. This demonstrates that, in contrast to Dekorver and Town's (2016) findings, undergraduates demonstrated metacognitive abilities needed to monitor their progress towards the goals set by their instructors, something that is important in the achievement of long-term goals that can be applied for success in the industry. This also concurs with George-Williams et al.'s (2018) study, which explained that British undergraduate students' acknowledgment of the importance of degrees focusing on long-term goals (such as building employability skills) matches the culture of British universities – in accordance with the Dearing Report (Dearing & Education, 1997), which required learning to be responsive to industry needs. All of the aforementioned opinions are in line with how lecturers ranked Kerr's practical work aims, as those ranked higher are all related to cognitive and manipulative laboratory skills.

Furthermore, lecturers explained that another aim of practical work is hands-on experience which demonstrates that practical work lessons were heavily focused on students 'doing' something with objects and materials. Lecturers supported the ranking of developing manipulative skills in Year 1 by explaining that life sciences are considered to be a practical subject, and that it is particularly crucial in early years to train undergraduates in 'doing things', so that as they progress to senior years they can design and work on their study based on previous learning. Moreover, one lecturer's expression, '[practical work] kills so many birds with one stone', highlighted that practical work has many benefits, and that those benefits justify the number of aims attributed to practical work for each year. Although the development of manipulative skills could only be seen amongst the top three aims for Year 1, it was evident that all of the aims ranked in the top three for each year involved the development of skills, starting with the manipulation of objects and equipment, and progressing towards the development of scientific thought skills such as problem solving, arriving at principles based on evidence, and observing accurately. As explained in one of the lecturers' interviews, not only do undergraduates need to be trained in techniques; it is also important to understand what is behind those techniques. As mentioned in the interviews and in agreement with findings from the literature, part of being a scientist is the development of transferable skills (Bretz et al., 2013) which are needed in a scientist's toolkit, such as resilience, teamwork, health and safety compliance, ethical conduct, and budgeting.

The ranking patterns observed, wherein aims at the top of the list for Year 1 slowly downgrade as undergraduates progress to senior years – were reflected in the discussion with lecturers, as they justified the progressive complexity of aims with undergraduates' development of independence and advancement; this theme emerged from interviews with faculty members in studies in the field of chemistry (Bretz, 2013). Lecturers were referring to the aims of practical work based on the undergraduates' year of study, as undergraduates in senior years were more independent and comfortable with working in the laboratory. This is verified by the way in which they ranked Kerr's aims for each year: lecturers explained that undergraduates in the first year are told what to do and are expected to follow their training, and to develop good investigative skills and habits. One lecturer further explained that undergraduates in the second year are expected to have already acquired the necessary skills to start working on problems set for them. This continues in Year 3, in which elements of self-driven experimental design are also introduced, to allow students to find facts by investigating and reaching necessary conclusions.

Lastly, in all three years, the promotion and maintenance of interest in the subject was found to be in the middle of the 10 ranked aims. The affective domain, according to Bretz (2013) study in undergraduate chemistry, pertains to feelings including enthusiasm and motivation, and includes attempts at 'making connections to the real world, engaging in collaboration and gaining independence' (p. 284). Indeed, interviews with members of staff revealed that confidence improved as undergraduates gained independence after progressing to more senior years. Interacting with their peers and sharing their experiences were deemed to be fun, and the application of real-life scenarios put learning in context – thus promoting motivation through the applicability of learned knowledge to real-world settings. This comes into contrast with what Dekorver and Towns (2016) discovered in their study, reporting that the objectives of faculty members and undergraduates were misaligned as undergraduates prioritised affective goals more often than cognitive ones such as feeling secure in their laboratory performance, which ran counter to expectations from the faculty.

Having explored the above aims of practical work in the department in which practical work lessons were observed, this now leads to the exploration of findings from the laboratory observations, which will provide answers to the remaining research questions. The first research question adopts an important strategy in the field of life sciences university education by thoroughly analysing the objectives of practical work from several angles. A comprehensive knowledge of practical work lessons is provided by taking into account the perspectives of undergraduates, members of staff and the actual execution in the laboratory. The scarcity of similar studies in the biosciences literature highlights the novelty and valuable contribution of this research in exploring the design and delivery of practical work in biosciences education.

Research Question 2

Are practical tasks effective in enabling undergraduates to *do* and/or *learn* what is intended?

An initial objective in the study was to investigate the effectiveness of practical work in undergraduate life sciences, and to understand whether it assists the development of scientific knowledge. As discussed in the previous chapters, effectiveness cannot be defined in broad terms, as its meaning might be perceived differently by different members of staff. For this reason, after laying the foundations by initially identifying the aims of practical work in the department of life sciences, and what undergraduates were intended to achieve through practical work lessons, real-life laboratory observations were made, to compare the tasks' effectiveness against what undergraduates do and learn. Through the findings of this research question, a unique contribution is being made by providing small case studies of practical work lessons, allowing for a detailed analysis of student learning outcomes and the specific content they acquire. By examining the focus of staff members, the study sheds light on their instructional strategies and priorities within practical work settings. This emphasis on both undergraduate learning and staff perspectives adds a novel dimension to the existing literature on practical work in biosciences education. The theoretical framework used (Millar et al., 1999; Tiberghien, 2000) allowed the evaluation of effectiveness on two levels, i.e. learning and doing, and in two domains, i.e. observables and ideas. Practical activities were differentiated from one another by the learning goals, which were categorised as knowledge development, skill development, and developing understanding of the scientific approach to enquiry. The way in which practical work lessons were designed played an important role in communicating task goals, information on experiments, what needed to be investigated, methodological approaches chosen, and the interpretation of results. All of the above aspects, based on this study's findings, contributed to the effectiveness of a practical work lesson. For answering the second research question of this study, findings will be presented in four parts, corresponding to the two levels and two domains of the theoretical framework used. Next, key attributes contributing to the success of practical work lessons observed will be explored further and discussed, with reference to the published literature.

What Undergraduates Do with Objects and Materials

Effectiveness at Level 1: Domain of Observables

> *"[…] students do with the objects and materials provided what the teacher intended them to do, and generate the kind of data the teacher intended. (Abrahams & Millar, 2008, p. 5)"*

The majority of practical work lessons focused on a goal concerned with the core essence of a scientist's identity – namely, practising laboratory skills (Seery, 2020; Reid & Shah, 2007) – by learning how to use laboratory equipment for observations and measurements, to follow and execute tasks in a standard practical procedure, and develop an understanding of the scientific approach to enquiry (Figure 18, Table 14); this is in line with the top three aims set for practical work lessons in Year 1 and Year 2 (Figure 19). Moreover, the acquisition of competency in laboratory skills was commonly discussed and is evident in interviews with staff members who view it as crucial for undergraduates' practical training for preparing their future employment in industry (Millar, 2004; Reid & Shah, 2007). This emphasis on skills development stems from the demand for scientifically proficient individuals in the job market, given the scarcity of scientifically skilled and experienced staff upon recruitment (Confederation of British Industry, 2011; Reiss et al., 2012). However, it is important to critically consider whether the current focus on laboratory skills adequately prepares undergraduates for the evolving needs of contemporary employers in the field. Rolfe and Adukwu (2021) argue that higher institutions have the potential to deliver updated bioscience knowledge and skills that are sought by contemporary employers in the field to change the political and economical landscape. Therefore it is crucial to critically assess the alignment between current educational practices and the demands of the industry to ensure that graduates possess the necessary competencies required for success in the industry.

Findings from this study highlight that practical work is effective in the domain of observables at Level 1; in developing observational skills. The majority of undergraduates demonstrated abilities in using equipment in a correct way, followed procedures to carry out experiments correctly, and followed instructions given; this enabled them to undertake experiments and generate data in the way that members of staff had intended, after being explicitly taught and guided. While the researcher moved around the laboratory, observations were focused on estimating the class proportion of undergraduates who were able to do as intended with objects and materials without being negatively impacted. Even though dissenting voices question whether skills development results from engaging in practical work, as difficulties in executing tasks can potentially hinder learning (Hodson, 1993; Johnstone & Al-Shuaili, 2001), it was evident that assistance from members of staff could support undergraduates in successfully carrying out experiments from start to finish. Support was offered throughout the entire lesson, as staff were assisting undergraduates in queries concerning the equipment and techniques that they had to use, as well as providing on-the-spot demonstrations and feedback to help undergraduates to correct their technique. For this approach to be feasible, the design of the laboratory lesson had to be structured so that the learning goals could be achieved while members of staff could devote time in assisting undergraduates. For this reason, in most Year 1 and Year 2 practical work lessons, undergraduates were mainly engaged in expository or discovery activities in which they were expected to follow a standard operating procedure and use equipment (Table 18). According to Urena and Gatlin (2012), the ways in which expository or cookbook laboratory lessons are designed give teaching space that allows members of staff to teach procedural and technical skills, since undergraduates already have access to the expected outcomes of experiments, and minimal thinking effort is required (Domin, 1999). However, while the observed outcomes demonstrate undergraduates' proficiency in following instructions and executing tasks, it raises questions about the extent to which their deeper understanding of the underlying scientific concepts is developed. The emphasis on procedural aspects and the availability of expected outcomes may hinder critical thinking and creativity in experimental design and analysis, but this is something that the biosciences departments can focus on at a later stage when undergraduates develop relevant conceptual and scientific skills that will give them the capacity to work on more open practical work lessons.

Furthermore, as undergraduates confirmed and further explained in their interviews, the acquisition of skills, and their competency in successfully learning and comfortably performing laboratory techniques, are based on following a detailed protocol – in this case, 'recipe style' instructions, being assisted by members of staff during experiments, as well as practising procedures and techniques repeatedly in order to automatise the process. Their interviews echoed the concerns raised by members of staff who highlighted the necessity of continuous training due to the risk of forgetting specific details over time, leading to inaccuracies in experiments and tests. This underlines the ongoing need for reinforcement and repetition to solidify skills. Staff members further emphasised the importance of providing additional lessons that require the repetition and utilisation of similar techniques, enabling undergraduates to build proficiency and familiarity with the equipment.

Even undergraduates who experienced difficulties during experiments, once assisted, could successfully complete their activity; this finding highlights the importance of supervision by members of staff who are present in the laboratory (Seery et al., 2018). This was also demonstrated in instances when undergraduates did not know what they were doing in the laboratory until a member of staff helped them to move forward.

Moreover, by receiving guidance while practising, undergraduates claimed that they could correct mistakes and clarify misunderstandings, so that through the repetition of procedures and the reuse of equipment they could familiarise themselves with laboratory techniques. Neurologically, incoming information which is repeated increases the number of neuronal synaptic connections in the brain and strengthens them; thus, they occur more automatically and processes practised can become automatic. This was further demonstrated through conversations with undergraduates claiming that they can vaguely practice specific techniques on their own unless they are following a protocol, highlighting their need for guidance to receive positive reinforcement until they feel comfortable in practising on their own. As members of staff explained, in order to learn skills, constant reinforcement is needed.

This is further explained by Johnstone and Al-Shuaili (2001), who stated that manipulative skills, when practised systematically so as to become automatic, allow undergraduates to focus on observing and interpreting results, rather than on merely executing manual tasks, as this prevents cognitive overload (Johnstone & Al-Shuaili, 2001). A student who finds operating equipment challenging will fail to focus on observations and careful data collection, which are practical work aims set for Year 2 and Year 3, as the density of non-substantial information, such as equipment troubleshooting, will create background noise that hinders performance (Johnstone & Al-Shuaili, 2001).

In order to prevent cognitive overload, in all Year 1 and Year 2 practical work lessons observed, activities were proposed and explained by members of staff and sometimes discussed prior to an experiment, mainly in Year 2; this would enable undergraduates to familiarise themselves with the activity to be completed and focus on acquiring the necessary skills, complete the experiment, and meet the goals set for the lesson. Members of staff put their efforts into and focused on assisting undergraduates in producing the desired results and completing the experiment successfully – an approach that was also observed in other studies (Abrahams & Millar, 2008; Warner et al., 2016).

In this study, the overwhelming consensus among staff members is the importance of practical work in science education at the university level. The staff emphasised that practical work serves as a means to develop essential laboratory skills and techniques, which are crucial for producing competent scientists. They highlighted the value of hands-on experience in the laboratory, stating that reading about scientific concepts alone does not equip students with the necessary proficiency in conducting experiments and performing tasks in a real laboratory setting. Self-efficacy, as highlighted by Cann (2014), plays a significant role in the affective value of practical work. The increasing expectations and limited exposure to practical work among bioscience high school students entering higher education make practical work challenging. However, practical work lessons provide undergraduates with the opportunity to acquire and develop critical skills necessary for their chosen discipline, which theoretical teaching alone cannot adequately provide (Cann, 2014; Dohn et al., 2016). Notably, research has demonstrated a positive correlation between self-efficacy in laboratory work and undergraduates' final exam academic performance, emphasizing the importance of self-efficacy in practical work (Dohn et al., 2016).

Previously, as mentioned in undergraduate interviews, amongst the various factors that contributed to the effectiveness of the practical work lesson at Level 1:o was the supply of a detailed protocol with a set procedure to be strictly followed with ‘recipe-style’ (Clackson & Wright, 1992, p. 41) or ‘cookbook’ instructions (Woolnough & Allsop, 1985, p. 80). Although the ‘closeness’ of the practical work tasks remained the same throughout Year 1 and Year 2 in terms of the supply of detailed instructions and guidance, it was evident from interviews with members of staff that the effectiveness of practical work at Level 1:o was reflected in the undergraduates’ independence as they progressed to senior years. Specifically, members of staff aimed to train undergraduates in developing good habits and skills throughout their first year so that they could focus on problem solving in Year 2, assuming that they had already acquired the necessary skills. Moreover, the use of expository-style experiments was justified due to the fact that undergraduates, especially in Year 1, do not have much confidence with which to be independent, and health and safety needs to be ensured to prevent accidents. In addition, the reason as to why the 'closeness' of practical work activities remained the same in Year 2, despite claims that undergraduates become more confident as they progress, was attributed to class coordination problems, due to the number of undergraduates and the inability to offer independent guidance frequently; this was also reported by Abrahams and Millar (2008). During interviews, members of staff explained that the effectiveness of a laboratory lesson indeed lies in its structure; and even though undergraduates, according to Abrahams and Millar (2008), are "told how to do it, and get a result" (p. 11), this does not negate the effectiveness of a practical work lesson, as laboratory classes should be 'student friendly' (Abrahams & Millar, 2008, p. 11) and staged in such a way as to guide learning (Schunk, 2012) through facilitators.

Lastly, concerning practical work effectiveness at Level 1:o, members of staff explained, as undergraduates previously reported, that repetition is important in enabling undergraduates to master laboratory skills. Since the acquisition of a laboratory skillset is one of the main aims of practical work, repetition contributes to its effectiveness as a practice. Members of staff highlighted: "Most students develop year by year with more practice and more experience and they become competent." Examining the findings of this study, the retention of skills learned in Year 1 was evident in Year 2 undergraduate lessons; this verifies what was discussed in interviews, as in all but one of the observed practical work lessons where practical skill competency had to be demonstrated, the tasks were successfully completed following set requirements (Figure 20). The effectiveness of practical work at this level is also reflected in the fact that in all Year 1 and Year 2 practical work lessons in which undergraduates had to use a piece of equipment or follow a practical procedure that they had not previously faced (Table 10), the majority could work with observables and materials in accordance with the intended goals of the task; this contrasts with earlier claims that students cannot apply the same skills in different contexts (Hodson, 1996). This study's findings in life sciences align with studies conducted in other fields explaining that exposure to instrumentation, combined with support from members of staff, had an impact on undergraduates' learning – thus indicating that greater levels of hands-on practical work experience demonstrated increased competency in using equipment (Richardson et al., 2012; Warner et al., 2016), and that decreased exposure was linked to a decline in undergraduates' skills (Grant, 2011). These collective findings underscore the importance of this research in highlighting the positive impact of practical work experience on undergraduates' learning outcomes in the life sciences.

Moreover, this study's findings disagree with those of Shallcross et al. (2013), who claimed that the time invested in practical activities does not indicate competency in practical abilities; although time per se, without a specific context and lesson structure, does not necessarily imply the development and maintenance of skills. Additionally, since one of the main aims of practical work in the department where practical work lessons were observed was to prepare undergraduates for future employment in the field, the findings do not support claims suggesting that cheaper and less time-consuming alternatives could be better options for the manipulation of materials (Abrahams & Reiss, 2016), since subject-specific skills and laboratory exposure are prerequisites for future employment in the sciences (Confederation of British Industry, 2011), provided that subject-specific skills refer to technical competencies (Kelley, 2021).

In the majority of practical work lessons observed, undergraduates were successful in gathering the required data and completing a practical work activity by using materials and equipment from beginning to end. Without assistance, however, undergraduates could not observe the outcomes or effects that members of staff wanted them to see. Again, the findings of this study highlight the importance of structured design of practical work lessons in that if the practical work lesson was structured in such a way that members of staff could spend time during and at the end of the experiment to go through the findings and explain observations, it would be less likely for undergraduates to leave the laboratory with misconceptions or the wrong results. As Abrahams and Millar (2008) explain, the effectiveness of a practical task in all domains and at all levels of the theoretical framework used depends on the effectiveness at Level 1:o, which requires the completion of a practical work activity; this aspect was prioritised by members of staff in this study, for reasons ranging from training undergraduates as part of their career preparation, to promoting skill development and acquiring the correct data to write an assignment. On this note, the findings are consistent with claims that content-independent skills, or non-technical skills (Kelley, 2021) – such as predicting, numerical dexterity, and critical thinking – are not prioritised (Hofstein & Lunetta, 1982). Instead, members of staff focused narrowly on the development of subject-specific practical skills, such as working with equipment and carrying out specific laboratory procedures, e.g. staining (Abrahams & Reiss, 2015), while undertaking practical work in the laboratory.

It has been argued that even though the goal is to teach scientific techniques, the assessment focuses on writing up a laboratory report – a task which, according to Seery (2020), reduces the value of time spent in the laboratory. Similar to Reiss et al.'s (2013) suggestion that a direct assessment of practical skills, including formal examination processes for practical skills, is a logical way of understanding whether students are capable of applying practical knowledge, the findings from this study showed that the acquisition of practical skills was apparent in subsequent lessons. This is shown in the fact that most undergraduates, belonging to the same cohort participating in this study throughout the semesters, could complete experiments and successfully work on techniques previously learned, since they were supported and supervised by members of staff throughout their experiments as part of their training. According to Hobbiss (2018 para.14)

> *"The problem is that, all too often, demonstration of a skill in the learned context is taken as indicating mastery of the skill in general, so lessons move on [...]"*

In agreement with the aforementioned quote, findings from this study showed that skill training was treated separately from data collection, as skills were developed with repetition and staff supervision (regardless of whether undergraduates could acquire the intended data), which indicates that the development of skills happens gradually and can coexist with other learning goals in the curriculum simultaneously, without their value being compromised. It is important to note that, with reference to the philosophy of learning by doing, practice or repetition was the most popular instructional method mentioned in the literature (DeMeo, 2001) – having been introduced by Faraday's pioneering book entitled *Chemical Manipulation* (1827) – as undergraduates practise several times to achieve an acceptable level of physical skill.

In the majority of classes, the results from data collection were discussed at the end of the experiment so that undergraduates would leave the laboratory with the correct data for writing their reports.

This study presents a novel approach by challenging the conventional notion of the laboratory as a space solely dedicated to theoretical knowledge development. As will be elaborated upon later, the unique aspect of this study lies in redefining the role of the laboratory, emphasising that it is not merely a space for theoretical learning, but rather a dynamic environment where practical skills and hands-on experiences are fostered and prioritised. By shifting the focus from theory to practice, this research contributes to a fresh perspective on the educational value of laboratories in promoting comprehensive learning outcomes.

The significance of practical work as a space for learning and skill development, rather than a mere treatment with expected effects, is highlighted in this study. Although the experiments were conducted in an expository-style manner with clear instructions, undergraduates succeeded in developing their technical skills and achieved what members of staff had intended them to achieve based on the aims set and prioritised for each year. Although DeMeo (2001) argued that skills are reflected by undergraduates' accuracy and precision, which will lead to a successful and safe completion of the experiment that they are undertaking, the findings from this research study indicate that even if the results acquired are not correct, discussion at the end of the laboratory leaves no room for erroneous data interpretations, and errors are corrected ad hoc during activities; this is a common and successful teaching method called the 'elbow instruction', or simply the provision of feedback (DeMeo, 2001). Continuous monitoring of students and supervision during experiments can improve the acquisition and development of skills (Gob et al., 1989), along with the introduction of a spiral curriculum (Bruner, 1960), in which undergraduates begin with simple manipulations which follow experiments involving complex techniques (DeMeo, 2001). Greek scientists have stated that "the mind has always been superior to the hand" (DeMeo, 2001, p. 373); therefore, little focus was applied to the understanding of skill development, in comparison to the development of conceptual knowledge. However, the influential "learning by doing" by Dewey (George-Williams, 2017; Dewey, 1938), which has been commonly linked with practical work, might not necessarily have to be translated into learning conceptual knowledge, as "experimentation undirected by theory would be a naïve inductivist approach to the acquisition of knowledge" (Caple & Martin, 1994, p. 18), but rather into learning science through practising skills. 'Science' and 'sciencing' should be clearly distinguished, with the latter being defined as the processes that scientists conduct which cannot be assimilated by inductive methods (Seery, 2018).

To summarise, practical work lessons in both Year 1 and Year 2 were designed and conducted in such a way as to assist undergraduates in undertaking tasks; for successfully developing their skills within the context of the experiment; and, ideally, albeit not necessarily, for generating the intended data in a particular practical work lesson. Findings highlight that the laboratory is a space where learning is cultivated through practical work lessons.

What Undergraduates Do with Ideas

Effectiveness at Level 1: Domain of Ideas

> *"[…] whilst carrying out the task, the students think about their actions and observations using the ideas that the teacher intended them to use." (Abrahams & Millar, 2008, p. 5)*

Effectiveness at Level 1:i refers to the mental process of thinking about observations and objects manipulated, by applying underlying theories to understand and explain what is not directly observable during a practical work activity. This, according to Millar et al. (1999), should be complementary to the undergraduates' direct involvement with objects manipulated. For example, whilst undergraduates can observe a slide under a microscope, thinking about the specimen and what parts are stained based on the molecular background of the cells constitutes 'doing with ideas'. Even though all practical work lessons observed were linked to specific scientific theories and concepts, the importance of scientific ideas in carrying out an activity well (Table 13) for both Year 1 and Year 2 was relatively low, as was the development of scientific knowledge (Figure 19, Table 10) *in the laboratory while undertaking practical work*. The novelty of these findings lies in challenging the conventional perception of practical work lessons as having immediate, direct results. These findings shed light on the need to reconsider the traditional notion that practical work should primarily focus on immediate scientific outcomes, but instead advocating for a broader perspective that recognises the importance of skill development and experiential learning. By questioning the traditional paradigm, this study contributes to a shift in understanding the true value and purpose of practical work lessons in science education. For instance, understanding the science behind staining while conducting an experiment, as already mentioned, did not hinder undergraduates' learning, given that members of staff took advantage of mistakes at the end of the experiment to teach about troubleshooting for future reference. Even though it became clear that undergraduates continued to follow procedural instructions while being unaware of the possible externally induced factors that could affect their final results, members of staff used this as an opportunity to contribute to the 'learning curve'. These findings corroborate the ideas of Bachhawat et al. (2020), who reported that through disruptions to experiments, undergraduates' problem-solving skills are developed, as questioning inconclusive results that are inconsistent with the expected data will give them the opportunity to consider and evaluate their methodology.

For instance, in this study, the use of immunofluorescent staining in practical work revealed a valuable learning experience for students. The interaction between the group of students, lecturer, and researcher demonstrated the importance of handling samples correctly and being aware of the sensitivity of fluorescent dyes to light.

These findings further support those of Holmes and Wieman (2018), which indicate that practical work activities did not enhance theoretical knowledge because undergraduates did not put the mental effort into reasoning and thinking, since they were merely following instructions in a laboratory manual. As Hodson (1996) explained, students "do not know where to look, how to look or how to recognise it when you have found it" (p. 118). While it is claimed to be necessary to successfully produce a result in order for learning to take place (Abrahams, 2011), it is not sufficient in itself to ensure that undergraduates learn what is intended by members of staff. The findings from this study suggest otherwise, since when undergraduates came across discrepant results, whether correct or incorrect, they were supported by staff members' guidance in explaining why their findings were unexpected, due to an error or their possible prior misconceptions, something highlighting their valuable role in the practical work lesson. It is important to note that undergraduates faced confusion only when their results were different from those of their peers; therefore, cognitive conflict was not generated due to insufficient knowledge of the scientific theories underpinning their experiments. Nevertheless, as previously mentioned, engagement with theoretical concepts through finding facts and arriving at principles was prioritised only in Year 3, when undergraduates would have enough experience and develop the expertise, refined schemata, needed to think and apply material learned in a scientific way. In Years 1 and 2, this internal scientific mental process expected of undergraduates in Year 3 was performed by members of staff through scaffolding. Expository-style activities have been criticised (Domin, 1999) for being non-realistic and hindering undergraduates from experiencing scientific methods; they are not intellectually challenged, since theoretical concepts are communicated to them by members of staff. As Roberts (2004) explained, expository-style practical work, in combination with scaffolding by members of staff, helps in developing undergraduates' conceptual lens through which they should learn to approach observations in the laboratory. Knowledge cannot be discovered if not conceptually understood (Hodson, 1996).

As previously discussed, most undergraduates were able to effectively complete the practical work task and do what was intended by members of staff at Level 1 in the domain of observables. In the majority of practical work lessons observed in Year 1 and Year 2, undergraduates were expected to report observations by means of scientific terminology (Table 15). For Year 2, in the majority of practical work lessons, undergraduates were expected to suggest possible explanations for the data. At this stage, it is important to take into consideration that for Year 1, the purpose of the experiment (Tables 26,27) was proposed by a member of staff – either with or without links made to previous work, or with class discussion to help undergraduates understand how the activity answers the research question of interest. For the majority of Year 2 practical work lessons, members of staff used the laboratory discussion to explain the purpose of the experiment . Even when there was no direct discussion on the purpose of the practical work activity, explaining the activity verbally helped undergraduates to understand the rationale behind their experiment, which is reflected in the fact that in 17 out of 18 lessons observed, undergraduates could explain what the activity was for and why they were undertaking it (Table 24). However, most undergraduates were not using scientific language to explain the theories and ideas underlying their actions, but rather only a few; and these students could only explain their observations after receiving guidance from members of staff, or 'borrowing' and using words that had been communicated by members of staff in their initial experiment introduction. These results are in agreement with Russel and Weaver (2011), who reported that students were reporting ideas in immature ways, thereby suggesting that they perhaps were unable to link their experience with scientific processes. However, it is important to mention that although the majority of undergraduates were not using scientific language, this did not necessarily mean that some of them were not thinking about the observables, in contrast to the aforementioned claims. Scaffolding is essential to assist students in connecting their thoughts with appropriate scientific language, fostering their understanding through positive reinforcement. This challenges the previous assertions and emphasises the importance of recognising the potential separation between language proficiency and cognitive engagement in practical work.

As Abrahams and Millar (2008) explained, thinking about observables within a theoretical framework is challenging, as the connection to what they are seeing is sometimes indirect. As can be observed in Tables 26 and 27, only in two Year 1 and three Year 2 practical work lessons did members of staff aim to help undergraduates to develop their theoretical knowledge on the topic chosen. Even though the majority of practical work lessons were effective in enabling undergraduates to do with observables and materials what was intended by members of staff, there is less evidence that undergraduates could think about their observations using underlying ideas *on their own*. The findings contradict Wellington's (2002) and Wang's (2005) argument that conceptual development can be promoted through practical work and tangible experiments, because theoretical concepts can be visualised. Additionally, active participation, as Millar (1989) explained, did not help undergraduates to identify theoretical ideas behind a task. As the interviews demonstrated , undergraduates, according to Hodson (1996, p. 118), “did not know where to look, how to look or how to recognise it when they [had] found it”

This issue might be attributed to the fact that in the lessons observed, undergraduates were not familiar with the underlying theories that members of staff intended them to use; or even if they were introduced to the ideas, they could not link the two domains together on their own, as performing science and understanding science are different (Wellington, 2002). This study has been unable to demonstrate that research-based practical work and independent learning can aid a better understanding of scientific theories – thus questioning Hodson’s (1990) claim that students cannot learn science via recipes, but only by performing science like a scientist through open investigations. Ideas do not automatically emerge from experiments (Brownell et al., 2015; Hake, 2002), and undergraduates cannot think about scientific theories without scaffolding (Bruner & Ross, 1976) – at least not in Year 1 and Year 2, during which undergraduates are still training in acquiring skills, thinking scientifically, solving problems, and carefully observing and recording; as stated in Kerr’s (1963) aims, ranked by members of staff. Undergraduates cannot understand the scientific process and obtain results in the same way that a professional in the field would do (Domin, 1999). If they are not taught how to do something, they will be unable to learn it by “acting it out” (Domin, 1999, p. 8). Although socio-constructivism-based learning, as supported by Meguid and Collins (2017), can have a positive impact on cognitive engagement, an understanding of scientific theories cannot be constructed unless it is previously learned, as students do not automatically grasp the theory behind a task (Watson et al., 2004). This result agrees with Pukkila (2004), who reported that undergraduates’ conceptual understanding is affected when class discussion is promoted, as well as activities that encourage an a priori formulation of hypotheses – the benefits of which will be discussed subsequently.

As previously described, undergraduates could not observe the outcomes expected; however, members of staff spent time during the experiments and at the end of the practical lessons to go through the findings (mainly for Year 1), and to explain observations, for conceptual development (mainly for Year 2), to ensure that the right ideas were introduced and clarified.

As demonstrated in the undergraduate on the spot interviews, it is not enough to see something; observations must also be made with the right conceptual mindset, because they become scientific only when bound to the relevant theoretical background (Johnstone & Al-Shuaili, 2001). Contrary to Schulz (1994), who reported that constructivism-based practical activities in secondary education showed a statistically significant improvement in learning in comparison to traditional activities, the findings from this study demonstrate the opposite, as theoretical knowledge could not be constructed merely through ‘doing’ and ‘observing’. Whilst undergraduates can think about the observables in any way that they wish, practical work tasks in this domain are effective only if the ideas intended by members of staff are used. It is important to highlight that, as can be seen in Table 12, adapted from Millar (2009, p. 6), undergraduates were expected to collect data on a situation and *then* think about how they might be summarised or explained. When examining the aims of practical work ranked by members of staff, they seldom prioritised the direct development of theoretical knowledge through the elucidation of theoretical work (Aim 7) *per se*, but rather the development of theoretical knowledge *through* problem-solving training (Aim 5) and arriving at principles (Aim 9). Even though the aims of practical work have been generally well researched (George-Williams, 2018), it would be wise to ask when the successful completion of these goals is expected to be observed. Why do effects of practical work need to be directly observed in the laboratory, rather than being regarded as a learning process with ‘pre-’ and ‘after-’ effects? Observations made for this research study revealed, as will be discussed later, that *practical work is not only an activity, but also a learning zone whose effects expand beyond the laboratory setting.* Research findings of this study adopt a different perspective by viewing practical work as an integral component of a larger learning zone, in contrast to the prevalent approach of treating it as an isolated and individual activity, as commonly observed in previous studies in the literature. This approach allows to explore the complex dynamics and interactions that occur when undergraduates engage in practical work, something that allows the analysis of the context in which practical work takes place, the surrounding learning environment, and the various support systems involved. Hirvonen and Viiri (2002, p. 306) aptly explained that conceptual learning cannot be expected to be a direct ‘side effect’ of practical work. Most importantly, learning should not be a direct side effect of practical work as an activity, as the activity itself, based on findings that will be discussed in more detail, requires more than undergraduates themselves being ‘hands-on’ – even more than ‘minds-on’.

To answer Research Question 2 using the lens of the theoretical framework at Level 1 and the domain of ideas, “whilst [students were] carrying out the task” (Abrahams & Millar, 2008, p. 5) in a literal sense, there is no evidence that undergraduates had a better understanding of underlying ideas and theories related to the practical work undertaken. This finding concurs with Osborne (2010), Hodson (1993) and White (1996), who reported that after pen-and-paper tests, no benefits were observed over traditional non-practical instruction. However, what this study offers it the perspective that the promotion of conceptual understanding was not considered to be one of the aims of undertaking practical work in the department; therefore, in that sense, members of staff neither expected nor intended undergraduates to develop theoretical knowledge inside the laboratory. A task is effective or ineffective based on what members of staff intend for undergraduates to think about while manipulating materials and observables. In Year 1, out of nine laboratory lessons, undergraduates in six practical work lessons (37–81% of the class) demonstrated that they understood, to varying degrees, the ideas that members of staff intended them to understand, depending on the way in which the lesson was designed (this aspect will be discussed in detail later). Similarly, undergraduates in six Year 2 practical work lessons (31–88% of the class) demonstrated some understanding of ideas. Objectively, an adequate understanding of ideas amongst the majority of undergraduates in the laboratory (51–100%), which fell in the borderline range – or within levels where answers were considered to be correct and aligned with staff's learning goals – was observed in only four out of 18 practical work lessons for both Year 1 and Year 2. It was clearly observed that even in those cases, undergraduates requested assistance from members of staff and were not adequately using scientific language to explain the concepts enquired; this supports Millar's (1998) claim that expert guidance is needed for students to understand the theory behind observations.

Even though the percentage of undergraduates who could demonstrate a conceptual understanding of the theoretical knowledge underlying their experiments was less than half in most cases, discussion after the experiment with members of staff ensured that undergraduates were aware of what they should remember from their experiment, as well as what the main findings were and how they could be interpreted. In cases in which there was no discussion at the end of the lesson, undergraduates with the wrong results and those who did not ask for guidance during their experiment left the laboratory with incorrect answers. Even though practical work can make theory seem more realistic, when guided instruction by a more experienced other is absent, undergraduates become confused, thus leaving the laboratory with misconceptions that will affect their learning (Parkinson, 2003; Roth et al., 1997). However, whilst all undergraduates demonstrated the ability to complete the activities, the importance of scientific ideas throughout the experiments was low and did not affect them.

It is important to acknowledge at this point that, as Abrahams (2005) explains, ideas and thoughts cannot be directly observed, but rather are inferred from dialogue and communication between undergraduates and the researcher. What undergraduates said was not only an indication of what they were thinking in relation to the experiments that they were conducting, but also demonstrated the fragmented information obtained from staff members' previous presentation of the task's theoretical background. It was therefore evident that in a large proportion of the laboratory lessons observed, undergraduates were not familiar with the underlying scientific ideas. However, even though the percentages show that many undergraduates demonstrated an understanding of ideas when answering questions related to the experiments that they were conducting, it was observed that some undergraduates who initially did not answer correctly could adequately link elements of theory with their practice, once they were assisted.

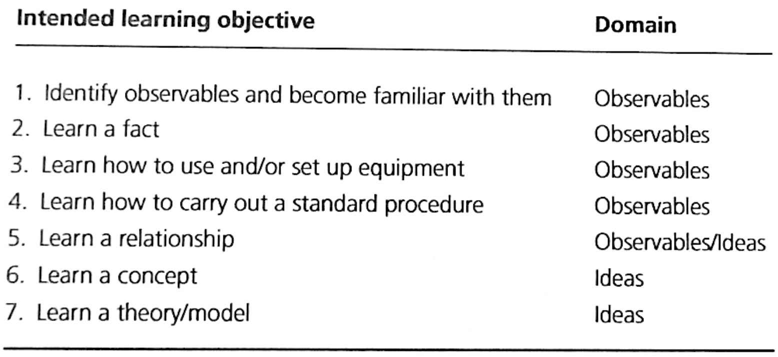
This result could perhaps be attributed to the fact that undergraduates did not know how to articulate their understanding during practical work lessons, as their schemas were not properly established and refined. Practical work has been argued to cause a significant cognitive load for undergraduates, as working memory is of limited capacity (Agustian & Seery, 2017), and if flooded can reduce information retention (Van der Zee et al., 2017). Since undergraduates were expected to process unfamiliar information in a limited amount of time (Tamir, 1991), the intrinsic load related to the level of difficulty of the information presented (Agustian & Seery, 2017) was expected to be high. According to constructivism, when information encountered in the laboratory is not aligned with pre-existing schemata, perturbation arises, leading to cognitive conflict and the learner seeking the restoration of balance and equilibration (Schunk, 2012). It would be unrealistic to expect the entirety of this cognitive process to happen in the laboratory while students are multitasking on executing an experiment.

What Undergraduates Learn about Objects and Materials Effectiveness at Level 2: Domain of Observables

> *"[...] the students can later recall things they did with objects or materials or observed when carrying out the task and key features of the data they collected." (Abrahams & Millar, 2008, p. 5)*

Having explored what undergraduates do with observables and materials, it is now time to consider what they learn about them. Effectiveness at Level 2 refers to what members of staff intend for undergraduates to learn and what undergraduates actually learn in terms of the observable properties of the materials that they are manipulating. Learning at this level, according to Abrahams (2011), is and can be expressed in terms of accepted scientific theories. The learning objectives of this study, based on the ranked aims of practical work for Years 1 and 2, were mainly concerned with promoting the scientific method of thought, the development of manipulative skills, accurate observations and recording, as well as problem-solving training. Taking into consideration the categorisation of intended learning objectives presented by Millar et al. (1999), in addition to the learning goals recorded during laboratory observations (Table 4.1a), it is clear that in the majority of practical work lessons for Years 1 and 2, members of staff designed activities that focused on and fell within the domain of observables. Based on the aims ranked by members of staff with regard to the purpose of practical work, it is only in Year 3 that some intended learning objectives fall within the domain of ideas, where undergraduates are expected to be involved in a process of finding facts via investigation and arriving at principles (Aim 9).

Table 41
Categorisation of learning objectives and their related domains (Millar et al., 1999, as cited in Abrahams, 2011, p. 77)



Intended learning objective	Domain
1. Identify observables and become familiar with them	Observables
2. Learn a fact	Observables
3. Learn how to use and/or set up equipment	Observables
4. Learn how to carry out a standard procedure	Observables
5. Learn a relationship	Observables/Ideas
6. Learn a concept	Ideas
7. Learn a theory/model	Ideas

As mentioned previously, the importance of undergraduates using ideas on their own while performing practical work in the laboratory was found to be very low, as members of staff were mainly interested in helping undergraduates to complete their experiments from start to finish, while they were the ones providing theoretical support with which to enhance understanding. Even in Year 2, learning objectives such as data analysis and drawing evidence-based conclusions accurately were expected upon completion of the experiment. In the domain of observables at Level 2, undergraduates could not learn about the directly observable properties of the materials that they were manipulating without guidance and scaffolding from members of staff. The extracts below further attest to this, and demonstrate that undergraduates in Year 1 and Year 2 could not observe what members of staff intended for them to observe without guidance.

In the domain of observables, members of staff claimed that recognising artifacts such as an air bubble on a microscope slide provides an opportunity for troubleshooting, and for the accurate judgement of what is expected to be seen in the material observed. However, members of staff placed a greater emphasis on scaffolding undergraduates and guiding them on the spot, so that they would leave the laboratory with no queries related to their experiment (rather than expecting the development of a conceptual understanding during the experiment). Members of staff, indeed, wanted undergraduates to develop their scientific knowledge; however, this was not expected to happen while performing practical work, as this was deemed to be unrealistic – thus verifying findings from other studies (Abrahams, 2011; Lazarowitz & Tamir, 1994; Hodson, 1991; Mulopo & Fowler, 1987; Hofstein & Lunetta, 1982; Blosser, 1983; Bates, 1978). This was clearly communicated by some members of staff who stated that lectures and practical work should be combined and should be done complementary, instead of being stand alone practices.

Indeed, a greater emphasis was placed on achieving objectives related to the domain of observables, including the development of skills and scientific thinking (Abrahams, 2011). Theoretical learning is more realistically expected to be developed through a combination of other teaching strategies (Abrahams, 2011), such as engagement with assessment, tutorials and lectures (this aspect will be discussed in more detail later). This does not imply that practical work activities should not be used to develop scientific knowledge; even though, as Abrahams (2011) explains, their effectiveness in that domain has been questioned in the science education community (Lazarowitz & Tamir, 1994; Hodson, 1991; Hofstein & Lunetta, 1982).

This discussion now turns to White's (1979) suggestion that the value of practical work lies in the way in which it provides an anchor – "a memorable event" (p. 385) that undergraduates would be able to hold on to – and later on, after their experiment, recollect in order to associate it with scientific ideas learnt through other teaching methods (Abrahams, 2005). At the university level, in contrast to research in secondary level education, no such 'memorable events' were exhibited, in which experiments would be considered "gore" or "visually, aurally and olfactorily distinctive" (Abrahams, 2011, p. 91); however, undergraduates reported that novel-context real-life scenarios triggered their interest and promoted their engagement (Johnstone & Al-Shuaili, 2001; Hodson, 1966), since they were applicable to everyday life (Edgeworth & Edgeworth, 1811). As reported in the literature, laboratory practices are often disconnected from current investigations and do not tackle real-life questions that interest learners (Dopico, Linde, & Garcia-Vazquez, 2013; Celine et al., 2022; Wu & O'Dowd, 2013; Whittle & Bickerdike, 2015). Consequently, members of staff should design educational lab practices that connect with real-world problems to stimulate learning gains, increase these activities' affective value, and foster undergraduates' understanding of undergraduate biology concepts (Dopico et al., 2013).

An assessment of what undergraduates said during interviews in the laboratory, regarding previous practical work lessons or the experiment they had undertaken on the same day, may not be a strong indicator of undergraduates' learning capacity concerning the topic learned; nevertheless, it provides useful evidence regarding what they will be likely to remember in the near future, since it is still fresh in their minds (Abrahams, 2011). However, the undergraduates' verbalisation of what they observed might be affected by a problematic translation of what they knew, due to unfamiliar terminology or anxiety (Schunk, 2012).

Hence, important terms and the experiment's purpose were introduced at the beginning. In discussing the reasons why practical work was advantageous for undergraduates, the word 'remember' was frequently mentioned in conversations; this was also reported in other studies (Denny & Chennel, 1986; Abrahams, 2011). In this study, some undergraduates expressed that their learning experience is enhanced through active interaction and tangible engagement. They believe that by physically interacting with objects or materials, they are more likely to remember the information. Additionally, they adopt a comprehensive approach by taking notes during the activity and later reading relevant theory to reinforce their understanding. On the other hand, others highlighted the importance of investing time and effort in the learning activity. They believe that actively engaging in the task provides an opportunity for critical thinking and deep reflection. According to those undergraduates, when they invest time and actively think during the activity, the information automatically stays in their mind. They emphasised the significance of active participation, interaction, and investment of time in the learning process. They therefore suggest that these factors contribute to better retention and comprehension of the learned material.

A more pessimistic view of the matter, regarding their experience with the reality of a laboratory lesson, was expressed by some undergraduates stating that they dislike practical work because they feel that the information they learn during the laboratory lesson quickly fades away once they leave. They indicated a difficulty in retaining the knowledge gained from the practical experience.Some also expressed a desire for the practical lesson to end quickly so they can focus on what they consider to be "real work" at home. They anticipated that they will forget everything they learned as soon as they leave the laboratory. Those undergraduates conveyed a sense of frustration and doubt regarding the effectiveness of practicals in terms of long-term learning. They perceived a lack of retention and express concerns about the practical knowledge not being meaningful or applicable beyond the immediate context of the laboratory.

Whilst in the interviews conducted it is evident that undergraduates in some practical work lessons could indeed remember and recollect information, claims attributing automatic information retention to merely being involved in ‘hands-on’ activities seem to be unrealistic; and, once again, as mentioned in the literature (Abrahams, 2011), this repeats the rhetoric surrounding practical work.

This rhetoric, however, is perpetuated not only by the majority of undergraduates engaged in hands-on activities, but also by members of staff explaining that people learn more by doing as it helps them remember if they do it in a constructive way rather than passively sitting in a lecture theatre. Similar findings were reported in statements seen in two large-case national survey studies concerning practical work (Thompson, 1975; Beatty, 1980; Abrahams, 2011).

As explained previously, it would be unfair to attribute grandiose properties and dramatic benefits to standalone hands-on activities. It is the delivery of those activities in a certain way within the context of the lesson that, based on observations, can have an impact on the effectiveness of practical work. According to members of staff, conducting experiments in close conjuction with lectures, and with the appropriate laboratory support, enables students to better retain the knowledge acquired.

In this respect, the findings appear to support the aforementioned view, because when observables from experiments are not linked to a theoretical background, information will most probably fade. Even though some studies report findings in which undergraduates could only recall information limited to specific details of an experiment but with no evidence of the use of scientific ideas (Abrahams & Millar, 2009), when discussion was embedded in the practical work lesson (an aspect not mentioned in the aforementioned study), it assisted pupils aged 13–14 in recalling what they did along, with their scientific explanations (Martindill & Wilson, 2015). During the interviews, it was evident that in the majority of practical work lessons, only less than half of the class could recall information to some extent and to varying degrees, usually after prompting from the researcher (Table 4.4) to trigger their memory. However, even if in the majority of practical work classes the recalling percentages were low to moderate, given the limited descriptive nature of undergraduates' explanations regarding observables linked with scientific ideas related to experiments, some lesson structure patterns were apparent which could possibly have an impact on the effectiveness of the lessons (a point that will be discussed in detail later).

The findings discussed so far indicate that practical work activities, in general terms, are successful in terms of getting undergraduates to do with objects and materials what is intended. Moreover, undergraduates could recall information on techniques practised in the laboratory.

As Abrahams (2011) stated, undergraduate recollections "tend to relate to what they did rather than why they did it" (p. 95). However, for the undergraduates to perceive and explain phenomena through scientific explanations, members of staff needed to guide them towards thinking about and seeing things in the way that was intended (Ogborn et al., 1996; Abrahams, 2011). This explains why some practical work lessons with introductions on the purpose of the experiment show evidence of potential improvement, in terms of how undergraduates understood and could remember theoretical concepts in the laboratory, as they were told what to observe and how to explain those observations (Wickman & Ostman, 2001). The success of undergraduates' ability to recall information from their experiments is not reflected in the effectiveness of practical work at Level 1 and in the domain of observables, but rather in what they can 'retain' from their learning experience in the laboratory; therefore, effectiveness depends on how members of staff stage the lesson, as the theoretical background needs to be pegged to observations, to allow the recallability of a visual experience with verbal knowledge (Abrahams, 2011; White, 1991).

What Undergraduates Learn about Ideas
Effectiveness at Level 2: Domain of Ideas

> *[…] the students can later show understanding of the ideas the task was designed to help them learn. (Abrahams & Millar, 2008, p. 5)*

"Learning in the domain of ideas is not discovery or construction of something new and unknown, rather it is making what others already know your own" (Millar, 2004, p. 6). Even though it is claimed that the role of practical work in scientific learning is to assist in linking the domain of observables with that of ideas (Brodin, 1978; Millar et al., 1999; Abrahams, 2011), the findings from this study show that in order for this 'linking' to succeed, undergraduates need to have access to both domains. For this to happen, undergraduates must not only receive guidance to successfully complete an experiment correctly, but also be scaffolded to think about their observations in a scientifically correct way (Abrahams, 2011; Lunetta, 1998; Gunstone, 1991). For this reason, as was observed, members of staff preferred to use expository-style experiments, as this allowed them to devote time – which was deemed to be vital (Abrahams, 2011; Tobin, 1990) – to helping undergraduates think about their activities by means of ideas intended to be used through scaffolding. Although Domin (1999) states that expository style practical work lessons, apart from easily and simultaneously engaging multiple students, requires minimal thinking, members of staff in the laboratories observed took advantage of the limited critical thinking requirements. Instead of expecting undergraduates to think *by themselves,* members of staff, through scaffolding, acted as knowledge facilitators (Urena & Gatlin, 2012) in helping them understand how to link what they were observing with the relevant ideas; something building undergraduates' metacognitive learning strategies (Cook et al., 2013). At this point, it is relevant to refer to Bloom's taxonomy, a theory that helps undergraduates understand how they processs learning material. Low-level skills can be covered in the laboratory as discoveries and observations of 'knowledge' along with 'understanding' is achieved with the help of members of staff (Bloom,1956). Advanced cognitive skills in this taxonomy, such as applying, analysing, synthesising and evaluating knowledge, can be accomplished at advanced stages when undergraduates begin to reflect on what they have learned, study material on their own, and write their assignments (Bloom, 1956). Even though Gunstone (1991) stated that less time needs to be spent on interacting with equipment and more time on interacting with ideas in order for practical work to help in theoretical knowledge development, focusing on the domain of observables through the acquisition of skills from practical work was prioritised in the department. However, Gunstone's statement is applicable to Year 3, during which undergraduates have already been trained in using equipment and performing scientific techniques; therefore, since they have automatised the processes, they can now focus on the domain of ideas. Similar to what Hodson explained for secondary school students (1992), undergraduates need to know where to look and how to look at it in order to make the necessary observations that will require interpretation.

Generally, the findings from this study showed that members of staff did not intend for undergraduates to learn about certain ideas on their own during practical work lessons. While in most lessons observed, only some undergraduates could recollect ideas related to their experiment, most of them were unaware of having learned something substantial; this supports claims from other studies (Abrahams, 2011; Gott & Duggan, 1996; Watson et al., 1995). Practical work per se might not be a direct means of learning scientific ideas; therefore, it can be argued as being no more or less effective than other teaching practices (Abrahams, 2011; Hofstein & Lunetta, 1982), but it can be an important part of a collective learning process consisting of a combination of different teaching and learning strategies that need to coexist to bring about the desired results. Those desired results, ipso facto, are not necessarily the objectives that members of staff discussed as part of the purpose of practical work, but rather objectives that they intended for their undergraduates to achieve as a result of studying towards a life sciences undergraduate degree. For this reason, even though undergraduates did not necessarily demonstrate understanding of scientific ideas during the practical work lesson (apart from specific cases discussed later), a synthesis of observations and ideas is expected to be demonstrated in the reports that they need to write as part of their assignments, as a result of reflective processing of the experience. However, in specific lessons where practical work was successful in helping undergraduates to understand and recollect ideas, there seems to be a pattern regarding how the lessons were conducted; these characteristics will now be examined.

Implications: Emerging Key Themes

Making Practical Work (More) Effective

In this part, the researcher will draw on practical work lesson features that were observed to have contributed to the effectiveness of practical work and which were considered to be good practice. Emerging themes will discussed extensively, along with providing a background on the way in which the lessons were structured, the role of members of staff in the laboratory, and the way in which undergraduates were assisted in thinking about objects, materials and ideas together. Although practical work lessons cannot be directly compared to one another, they will be carefully inspected so as to understand whether any patterns arose in lessons, in which 'most' undergraduates demonstrated the development of skills, the use/understanding of ideas, and the ability to subsequently recall information.

Lesson Structure

Initially, it was observed that practical work lessons with clear specific objectives achieved their intended outcomes. Particularly, the two practical work lessons in Plant Biology that aimed to improve undergraduates' knowledge were successful. According to the findings, most undergraduates demonstrated an understanding of concepts throughout their activities and were able to recall details about observations and experimental concepts in subsequent lessons.The implied relevance assigned to scientific ideas (varying from fairly significant to crucial) reflectd the value placed on introducing theoretical concepts even though one of the two lessons, Animal Nutrition and Zoology, did not specifically attempt to promote scientific understanding. This was mae clear in class discussions that took place before the practical activity during which undergraduates received the necessary theoretical background knowledge for the experiment. These findings have important implications for the design and implementation of practical work in undergraduate education. For practical lessons to be effective, objectives must be clear since they direct undergraduates toward achieving specific learning outcomes. Additionally, even when the main goal may not be the acquisition of knowledge, incorporating theoretical conversations before engaging in practical work activities can improve undergraduates' understanding and recall of scientific concepts. Members of staff can maximise the learning potential of practical work lessons by recognising the implicit importance of introducing concepts and providing theoretical background. In order to ensure that practical work effectively adds to undergraduates' total scientific knowledge and understanding, this insight can be used to drive instructional strategies, curriculum design and the creation of support resources.

However, as observed in Year 2, class discussion on ideas before the practical activity was also observed in lessons in which only a few undergraduates demonstrated understanding of ideas and recollection of information when asked (Molecular Biology, Biochemistry, Biochemistry II). Respectively, in Year 1 there was no class discussion before the practical activity for the two Microbiology lessons, but there was evidence of understanding and recollection among 'some' undergraduates. Comparing common characteristics between the only four Year 1 and Year 2 courses in which understanding and recollection were observed among most undergraduates, it is evident that certain structural similarities might have contributed to the effectiveness of the practical work lesson in terms of developing scientific knowledge and being able to later recall it. Providing detailed instructions on the practical work activity and explaining it orally, discussing its purpose, and discussing the underlying ideas prior to the experiment, are combined lesson characteristics observed in Year 1 Plant Biology lessons and Year 2 Animal Nutrition and Zoology. Undoubtedly , undergraduates acknowledge and value carefully planned practical work lessons as they find them beneficial to their learning as when everything is properly structured, they felt that they could get enough information from the guidebook and then from members of staff along with detailed steps on what to do and what to see. What is more, undergraduates believed that a well-designed practical is one that is placed in context and also prepares them before the beginning of the experiment providing relevant information that will be utilised during the experiment. Lastly, undergraduates stated that it was important for them to have the right answers and engage in discussion with members of staff regarding those before leaving the laboratory. Based on undergraduates interviews, findings resonate with those in Bruck and Towns (2013) where a need for training of teaching assistants was highlighted as their role was imperative for undergraduates and their understanding of the practical work lesson.

Additionally, class discussions following the practical activity to confirm what undergraduates saw, along with explaining observations, might contribute to the high percentages of undergraduates remembering information in subsequent lessons. Even though lectures cannot always be timetabled to be delivered before practical work lessons, and as a result undergraduates cannot remember relevant information, providing information related to the scientific ideas underpinning an experiment helps undergraduates to make connections between abstract observations and scientific explanations.

As stated above, one of the advantages of practical work was that when combined with lectures, it enabled undergraduates to acquire a scientific background with which they could support and make sense of their observations in the laboratory as it helped them getting familiar with theories, visualise written information, and backing up lectures by filling conceptual gaps.

Furthermore, in Year 1 Cell Biology and Year 2 Immunopathology, percentages for understanding show that nearly half of the class could demonstrate an understanding of ideas while working on their experiment; this indicates that structural characteristics which are similar to those in successful practical work lessons mentioned earlier, could help undergraduates to 'do' with ideas what was intended by members of staff.

The findings suggest that knowledge development was not the primary goal of practical activity lessons in the majority of Year 1 and Year 2 lessons where limited understanding and recall were noted. The absence of class discussions on experiment-related concepts before the practical activity in Year 1 prevented undergraduates from using newly introduced theories during the experiment (Biochemistry, Microbiology, Histopathology). Similar to Year 1, members of staff only intended for undergraduates to develop their knowledge in Pharmacology and Biochemistry among the lessons were understanding and recall were weak. Despite the fact that both lessons included laboratory discussions, practical work did not effectively facilitate the understanding of ideas. This could be attributed to the challenging nature of practical work protocols and the inclusion of in-depth case studies in both the Pharmacology and Biochemistry lectures. These elements demanded cognitive engagement with subject-specific previous information. Furthermore the processes required complete concentration and involved precise measurements, such as determining plasma clotting intervals for instance. In order to make sense of the findings, such as the effect of dietary choices on blood clotting issues, careful interpretation of non-directly observable data that needed engagement with scientific ideas and principles was also important. During these classes, the undergraduates had to use both of their "hands-on" and "minds-on" skills as they simultaneously acquired new clinical laboratory procedures and became accustomed to case studies that involved solving problems. Given the restricted time for information processing, this required involvement with theories they were uncertain about applying independently. One participant who was a student brought out the difficulty of extended practical work sessions that required a lot of reading and created confusion.

The design of practical work classes for undergraduate students will be significantly impacted by these findings. Prior to the practical exercise, care should be taken to allocate enough time for class discussions that teach essential theoretical concepts. Undergraduates' engagement with scientific concepts can also be increased by balancing the cognitive demands of the practical protocols and providing clarity in result interpretation. To get the most from students' learning during practical work, it is essential to take into account their cognitive load and how comfortable they are using ideas independently.

Similarly, members of staff explained that undergraduates “are overwhelmed because they need to do too much at once”. In the remaining practical work lessons in which understanding and recalling percentages were low, neither the development of knowledge nor the discussion of ideas was regarded as being important before the practical was attempted (Year 1: Microbiology, Histopathology; Year 2: Immunopathology, Biology of Diseases, Molecular Biology, Biochemistry).

However, it is important to acknowledge through the findings presented that a practical work lesson should be structured in such a way as to address the complexity and demanding learning environment of a laboratory (Agustian & Seery, 2017). The quick introduction of a large amount of unfamiliar information or an expectation to process information quickly in a limited amount of time triggers cognitive overload, as great mental effort is exerted due to overwhelming demands that have not been adequately assessed when designing the lesson. By addressing the triarchic model of cognitive load (Sweller, 1988), intrinsic load and extrinsic load related to the difficulty of the information exposed and to the way in which information is presented respectively (Agustian & Seery, 2017) are reduced if undergraduates have more organised schemata through the pre-introduction of required information before entering the laboratory. Even though Domin (1999) claims that students engaging with expository activities do not critically assess the validity of their findings but rather trustingly compare them to expected results; they are not expected to do otherwise based on this study’s findings as they are progressively training in learning to link theory to what they observe. Additionally, the absence of intellectual challenge (Domin, 1999) due to the ‘spoon-feeding’ element most prominent, according to George-Williams (2018), in Year 1 is what helped undergraduates in this study’s laboratory observations to start linking theory to observables. Domin (1999) further adds that students are unable to develop their inquiry skills due to aiming in obtaining correct results rather than thinking about processes and secondly due to not having enough time for processing the experiment by linking it with supporting theory; they are unable to engage in processing prior knowledge and identify the relevance of their experiments. However, findings from this study demonstrated that the concerns reported by Domin (1999) can be controlled and results indicated a positive link between those teaching approaches and successful understanding as undergraduates need to first master the development of scientific skills and making informed conclusions. Inquiry levels in the rubric by Fay et al., (2007) and Seery et al’s. curriculum model (2019) demonstrate that different stages allow members of staff to slowly increase undergraduates’ responsibilities while doing practical work as each stage’s outcome should support experiences achieved in previous stages (Seery et al., 2019). Even though expository, and progressively, discovery learning types of enquiry have been the most traditional and most criticised teaching methods (Domin ,1999) it is their minimal thinking requirements that allow space for external interventions. As Linn (1977) argues, it is unrealistic to anticipate undergraduates to simultaneously understand new information, handle unfamiliar equipment and use their problem-solving skills to approach a novel situation. The first factor that can be controlled lies in the structure of the practical work lesson, as discussed in this section, which should take into consideration the cognitive load theory as working memory is of limited capacity (Agustian & Seery, 2017) of auditory and visual information (Van der Zee et al.,2017) and if flooded can lead to working memory overload (Domin, 2017) and problematic information retention (Van der Zee et al.,2017). A balance in the novel information introduced verbally before and after the experiment and consistency in the material provided both verbally and in written form, as part of the experiment protocols, will decrease the amount of internal cognitive load that would otherwise overwhelm the working memory with unfamiliar information. This is due to the reason that mental schemata, especially in early year stages such as Year 1, are not adequately formed as the level of undergraduates’ subject expertise is minimal. Additionally, extraneous load related to the way information is presented can be simplified and aligned with information from supportive material so that undergraduates can be maximally supported when an external experiment difficulty is encountered. Automatisation of schemata and incorporation of information in long-term memory, referred to as Germane load, can be eventually demonstrated in undergraduates’ characteristics in their final year of studies where both technical skills and conceptual development have been adequately built. As a result this can be implemented in experimental and scientific research of the ‘unfamiliar’, as demonstrated in the curriculum model by Seery et al., (2019) as adequate conceptual mental resources will be built to a sufficient level. In summary, the structure of the practical work lesson should contribute in such a way so that the cognitive load will range within levels that will challenge undergraduates enough so that cognitive conflict will trigger resolution for accommodation and assimilation to take place, but not overwhelm the working memory to such levels that will hinder learning. The learning environment needs to be designed in such a way to make important aspects discoverable so that members of staff can scaffold the learner within their zone of proximal development. Additional factors that can be controlled within expository practical work experiments such as the contribution of members of staff and the requirement of pre-laboratory activities will be discussed in forthcoming sections.

Members of Staff

An important finding emerging from both observations of and interviews with undergraduates was that members of staff were regarded as being valuable in the laboratory, as their guidance improved the laboratory experience while conducting experiments. In the literature, it was evident that through practical work members of staff as instructors can equip undergraduates with valuable bioscience skills and foster a conceptual understanding of scientific principles and models (Rolfe & Adukwu, 2021; Miller, Hamel, Holmes, Helmey- Hartman, & Lopatto, 2013). As explained, demonstrators walking around the laboratory and providing explanation so as to aid undergraduates in going from point A to point B by confirming about the validity of their findings assists them in developing their skills year by year.

Thus, members of staff were moving around and ensuring that undergraduates would successfully finish their experiments with the desired results, and understand the scientific concepts behind their actions. Specifically, they compared their interaction with undergraduates to that between an apprentice and a more knowledgeable other, indirectly demonstrating the integration of the Vygotskian theory of social constructivism in their curriculum. As an undergraduate accurately explained, demonstrators act like scaffolds and provide relevant knowledge needed to put all the puzzle pieces together.

Members of staff adopt roles perceived “not as mere facilitators or intermediaries of student learning but as active participants in the learning environment” (Urena & Gatlin, 2012, p. 142), as they are not simply passively lecturing undergraduates, but rather are engaged in the learning process by being involved in discussions, using prompting questions, and directing undergraduates. Their importance is acknowledged by Lazarowitz and Tamir (1994), who found that members of staff are regarded as being one of the most influential factors in the laboratory and that failure to take advantage of their role can hinder the development of learning (Herrington & Nakhleh, 2003; Pickering, 1988).

Furthermore, members of staff explained that practical work lessons resemble a “show that needs to be choreographed” (Staff 4), as the time is limited and the lesson needs to be structured in order to guide undergraduates and ensure that they will not miss the point of the experiment. Interviews demonstrated the alertness of members of staff in supporting undergraduates when needed. Demonstrators and technicians were expected to intervene during experiments so as to let undergraduates connect theory with practice in moments when they start wondering ‘what is this for?’ as it is unlikely they can understand theory by just doing experiments.

While discussing the effectiveness of practical work with members of staff, it was observed that in the most successful practical work lessons, the number of undergraduates in the laboratory was small, whereas a larger class size had an impact on undergraduates’ learning. This was confirmed by a member of staff explaining that enquiry-based experiments, in contrast to expository ones, are limiting as the number of undergraduates in most practical lessons is too big, and for this reason class coordination challenges occur as they cannot attend to the needs of every person. Similar findings were reported by Bruck and Towns (2013) as members of staff stated that they encounter difficulties when instructing courses with big undergraduate enrolments.

As has been highlighted so far, members of staff actively contribute to undergraduates’ journey of developing as scientists when they embark on their undergraduate programmes. They can promote an environment in which undergraduates can advance and start becoming independent and autonomous learners (Urena & Gatlin, 2012). Scaffolding during the learning stage ensures that trainees (in this case, undergraduates) will need less assistance over time, and this is achieved by partnering experienced others (members of staff) with novices (undergraduates), while integrating modelling and imitation through social interaction (Nicolic et al., 2015). Thus, members of staff acted as models of the internal scientific voice that undergraduates should develop by Year 3. Thinking was carried out for them, to help them adopt the scientific way of thinking and learn how to link observables with ideas. Undergraduates' training in the laboratory, combined with corrective feedback from members of staff, promotes learning (Pintrich et al., 1986). Members of staff , as experts, use language as a tool supporting learning (Duncan, 1995). Even though Piaget and Vygotsky acknowledge the social influences affecting learning, those influences are understood in different ways. Piaget, as interpreted by Duncan (1995) regarded external influences of the sociocultural circle, such as that of members of staff introducing undergraduates to the laboratory culture, as factors that create learners' internal disturbances so as to trigger cognitive conflict therefore awaken their need for equilibration and thus accommodate novel information that confronts their preconceived ideas. Similarly, Vygotsky (1978) believed that cognitive conflict triggered by instruction assists learners in entering the zone of proximal development, as it will be discussed in forthcoming sections, and in that zone learners will be assisted by members of staff so as to cross the zone, and according to Piaget accommodate newly introduced information to progress and understand concepts. Teaching based on constructivism , as Taber (2011) explains, should provide to undergraduates a "database for learning" (p.57) and guide the learning process as only when a learner identifies a discrepancy between their preconceived ideas and new experiences will trigger the internal process of modifying these ideas. Members of staff should not be concerned with criticism concerning constructivism advocating direct or minimal instruction but instead optimum levels of instruction;" Effective teaching needs to be both student-centred and teacher-centred" (Taber, 2011 p.57). Additionally, Xu and Talanquer (2011) highlight the need for explicit intervention by members of staff to improve the quality of undergraduates' reflective thinking regarding conceptual development. They add that members of staff, as teaching assistants, need to model reflective thinking and carefully scaffold undergraduates with guiding questions to motivate and press them to discuss about scientific concepts otherwise they will focus on procedural and methodological challenges occurring. Sustaining group conversations with undergraduates regarding ideas, materials and evidence-based explanations will help undergraduates focus on conceptual issues rather than procedures, something that undergraduates reported in their questionnaires in the following sections.

Independence and Progression

It was evident that members of staff were assigning different aims based on the undergraduates' year of study. As they were progressing to senior years, undergraduates were described as being independent and more comfortable, which demonstrates the effectiveness of practical work through undergraduates' progressive development. In member of staff interviews, the approach to teaching practical work laboratory skills in the first three years of universities was discussed. There was agreement that in the first year, undergraduates need to be taught the basics and develop good habits to avoid accidents. They also believed that in the second year, undergraduates should be given more autonomy to work on problems independently while others suggested that this is something that has to be introduced in the third year, with caution, to ensure that undergraduates do not lose the opportunity for learning through problem -solving. The ultimate goal was to prepare undergraduates for independent research projects in their final year.

The result that emerged from the interviews with members of staff is in line with the enquiry rubric presented in Seery et al. (2018). Level 1, according to Seery et al. (2018), is equivalent to the expository approach in which information is being provided at the beginning of the lesson along with the methodology, but the solution remains to be constructed by the undergraduate; this method applies to the Year 1 and Year 2 practical work lessons observed. Level 3 enquiry approaches based on Seery et al. (2018) allow undergraduates to choose their research question, design the methodology, and interpret the results – which resembles Year 3 undergraduate final-year projects. The enquiry levels in the rubric can be used successively so as to slowly increase students' responsibility while performing practical work. As Lott (2011) explained, scientific enquiry can be introduced at different levels, but in order for undergraduates to advance to a level at which they acquire autonomy and the freedom to work with open enquiry, they must first master scientific skills such as formulating hypotheses, planning their procedure, using equipment and scientific techniques for gathering data, and making informed empirical conclusions – similar to the way in which members of staff in the studied department structured the practical work goals for each year. According to Lott (2011), teaching students throughout the levels of inquiry, from expository to enquiry, should be done subtly, slowly and gradually, so as to prepare students accordingly and alleviate stress, instead of using the "jump in to either sink or swim" approach (Lott, 2011, p. 33). Every step gives students more freedom and more control over their practical activities. Students might be used to being told what to do (as in cookbook experiments); but by slowly building enquiry and technical skills, they can move to higher levels of enquiry. Although research-based approaches at higher levels of enquiry give undergraduates an authentic scientific experience in terms of understanding scientific practices and demonstrating what a career in the sciences would look like, undergraduates explained in their interviews that they developed gradually until they were able to work independently (Wang, 2005), and could then progress from expository-style experiments.

Prerequisite Learning

During practical work lessons, members of staff and the researcher realised that undergraduates who studied the experiment and the related scientific theories prior to entering the laboratory could engage and perform better, as they did not become overwhelmed by new information that had to be processed in a limited time before conducting an experiment. Cann (2014) explains that simple online interventions and pre-laboratory preparation in increasing undergraduates' engagement with laboratory activities aim improved academic achievement in bioscience courses. They believed that practical work is like solving a puzzle where undergraduates need to connect the dots to understand the theory behind the experiment, emphasising that undergraduates need to be adequately prepared with theoretical knowledge before undertaking practical work. Without prior knowledge, undergraduates will struggle to understand the reason behind the experiments, despite following the instructions correctly.

Most of the time, as discussed in previous sections, undergraduates lacked understanding of the main theories and could not recall them. As a result, undergraduates who were confident in continuously answering questions correctly during the laboratory interviews were asked about their ability to combine observables with theories, and with which approach they achieved that. What they stated was that revising material before entering the laboratory helped them to reinforce the theory and prepare them for their experiment. Some of them even acknowledged consciously that not knowing the theory does not help when they need to reach conclusions and understanding therefore they just need to do it, they need to read beforehand.

Other undergraduates who could not correctly answer subject-related questions admitted that they did not know what they were looking at, since they did not read about it. Although it has been reported that undergraduates who were taught about scientific concepts prior to entering the laboratory could still find it difficult to link observables with ideas (Abrahams, 2011; Hart et al., 2000), this does not negate the importance of studying before the experiment, as undergraduates will be better prepared to receive guidance from members of staff, and be receptive when participating with them in linking observables with ideas.

The reticular activating system in the brain is a mechanism which makes perception meaningful because it filters information; this helps undergraduates to focus on what is important based on what they have previously studied and have prepared their minds for experiencing while conducting their experiments. It also excludes trivial information inputted that creates background noise (Wolfe, 2010), and which would have otherwise created confusion. Several factors influence the filtering process, starting from perceived importance, such as members of staff providing an introduction prior to the experiment and explaining what is important, as well as points to which they should expect to pay attention. The brain tends to focus on input that is regarded as being novel or different from what is expected; therefore, if undergraduates study material beforehand and understand the basic concepts of the scientific ideas behind their experiment, as well as procedural information that they will encounter, then the practical work lesson will not be so overwhelming, and they will be able to focus on more substantial stimuli (Schunk, 2012). Even though this attention system mainly operates unconsciously, the aforementioned practices can help to focus undergraduates' attention towards what matters.

Linn (1977) argued that it is unrealistic to expect undergraduates to simultaneously understand a new subject, handle unfamiliar equipment, and use their problem-solving skills to approach a novel situation. An expository-style practical work lesson removes the aforementioned background noise of the unknown that would put immense pressure on undergraduates, and allows time for members of staff to provide their guidance. Undergraduates, for their part, need to prepare before entering the laboratory so as to prevent what Domin (2007) described as "working memory overload" (p. 150). Indeed, undergraduates need to be actively engaged with their experiment while handling equipment, following a protocol, and manipulating projects; therefore, it would understandably be difficult for them to simultaneously apply prior knowledge (Johnstone, 1984). However, if undergraduates are familiar with the underpinning theories, they will be more ready to accept input from members of staff, thus allowing the promotion of conceptual development. Additionally, if they are familiar with the instructions, they will be able to conduct experiments with greater cognitive engagement. Again, cognitive overload is highlighted as an immense cognitive demand being placed on working memory as a result of either presenting a large amount of unfamiliar information quickly, or expecting undergraduates to process a large amount of information in a limited amount of time (Abrahams, 2011; Tamir, 1991). Intrinsic load is limited when undergraduates have background information on what they are learning in the laboratory, as familiar information will already be organised as a schema in working memory and, therefore, will enable easier processing (EIP, 2016). Given the fact that laboratories need to be treated as standalone practices due to difficulties in timetabling lectures prior to practical work classes (Agustian & Seery, 2017), information is required to be presented to students before entering the laboratory as a way of preparing them. Indeed, Kirk and Layman (1996) reported that students felt better prepared for their experiments and understood concepts and processes better when they used pre-laboratory guidelines. Additionally, similar feelings of 'readiness' were reported by students who were forced to complete required work before entering the laboratory (Chittleborough et al., 2007; Kolodny & Bayly, 1983; Starkey & Kieper, 1983).

Similar to conceptual development, previous studies found that preparing students on technical skills as part of a pre-laboratory activity enabled them to experiment with procedures that they would encounter in the laboratory in advance (Agustian & Seery, 2017), through either simulations (Nicholls, 1999) or video demonstrations (Simpson, 1973; Watson, 1977). Less scaffolding (Powell & Mason, 2013) was required as a result of the aforementioned interventions in preparing students for entering the laboratory.

Therefore, members of staff have to determine how much content knowledge is necessary for undergraduates to be able to mentally engage with their practical work activities and to what extent they have acquired this prior to entering the laboratory as investigation is conceptually dependent and cannot occur in a knowledge vacuum (Johnstone and Al-Shaili,2001) Undergraduates entering the laboratory without preparation will likely spend time in fruitless learning. Laboratories as learning environments are very expensive so they should be used to their potential with time spent productively as they would otherwise be "a massive sink of scarce resources" (Johnstone and Al-Shaili,2001 p.49) Even though it was evident that undergraduates can survive practical work lessons comfortably without content knowledge , as demonstrated in this study's laboratory observations (Table 13, Ch. 4), pre-laboratory activities must prepare them in actively participating during practical work activities, something advocated by a number of tertiary members of staff (Garatt, 1997; ; Nicholls, 1999; Carnduff & Reid, 2001; Johnstone and Al-Shaili,2001)

In-laboratory Discussions

In order for undergraduates to do and learn what the teacher intended with objects and materials, there is evidence that multiple presentational methods of procedural information alleviated cognitive overload and allowed them to process information more easily (Abrahams, 2011). The fact that information was presented in multiple ways during practical work lessons – such as in written format as a protocol, as slides on projector screens, and verbally via the lecturer – helped undergraduates to engage, as information did not repeat itself (Scagnoli et al., 2017). The fact that the only textual information present was that of the experiment's protocol blended well with the discussions led by the lecturers before and/or after the practical work lesson, as it prevented the risk of cognitive overload, given the fact that working memory has a limited capacity of auditory and visual information, and this can impact information retention (Van der Zee et al., 2017). As explained neurologically, sensory input (apart from smells) is sent to the appropriate lobe of the cerebral cortex for processing. For example, an auditory stimulus such as a lecturer talking before the experiment will match information on the experiment protocol stored in memory, as part of a pattern recognition mechanism (Schunk, 2012); thus, it will make information more solid. Explanations received by members of staff serve as environmental input for undergraduates. By being exposed to discussions, undergraduates learn new ideas and integrate them with already-formed conceptions. This cognitive activity helps to build synaptic connections in the brain and wires it to start using information in new ways. In fact, introducing scientific concepts and using them during the practical work lesson, while undergraduates are conducting their experiments, assists them in envisioning the underpinning theory (Solomon, 1999), and this enables them to imagine what is happening beneath observations (Abrahams, 2011).

The interplay between observations and ideas before, during and after the experiment can enhance the effectiveness of a practical task. Students, therefore, reported that pre-laboratory discussions prepared them for understanding their experiments and also assisted them in linking pre- and post-laboratory work for their analysis (Agustian & Seery, 2017; Limniou et al., 2009; Kolodny & Bayly, 1983; Johnstone et al., 1993); they also encouraged minds-on activity during their experiment (Harisson, 2016). When undergraduates engage in discussion with fellow students or members of staff, it deepens the information they have learned as elaboration of learned information encourages rehearsing of knowledge, something that actives the implementation of learned information into the long-term memory (Schunk, 2012). Based on the constructivism learning theory, undergraduates do not learn passively but create their learning from experiences and interactions with others in an effort to gain awareness of their environment (Forrester et al.,2001; Schunk, 2012). As explained in Vygotsky (2012) academic or scientific concepts are not automatically available and transferable from one mind to another therefore language should be used in order to help learners develop cognitively. Rather than placing the onus on the learners constructing their own learning with limited guidance through discovery, undergraduates should be exposed to several overlapping partial representations, as explained in neuroconstuctivism (Hobbiss,2018), which can be enhanced through explicit instruction by repeated exposure through introductory, in-laboratory, and conclusory discussions.

Even if expository laboratories do not completely cover the desirable features of real-life laboratory work, inquiry laboratories would be impracticable at universities, especially in early years (Johnstone & Al-Shaili, 2001). Expository laboratories with substantial scaffolding can go a long way towards achieving the desirable aims of laboratory instruction.

Research Question 3

Does practical work contribute towards meaningful learning?
If so, to what extent does the affective value contribute to that meaningful learning?

Meaningful learning, as Ausubel explained, occurs when new information is successfully linked to a student's previous and existing knowledge (Bretz, 2001) in a substantive manner, rather than being memorised as rote learning. In order for meaningful learning to be achieved, "(1) students need to *choose* to have some relevant prior knowledge that relates to the new information that needs to be learned; (2) material to be learned must be meaningful on its own; and (3) students *must consciously choose* to incorporate this meaningful material into their existing knowledge" (Bretz, 2001 p.3). In the interviews with members of staff, and in accordance with Bretz (2001), it was clear that they all agreed that they could not control how undergraduates chose to study at university, but they believed that practical work could provide learning opportunities that undergraduates need to take advantage of:

> *[...] We provide it all and they have to take advantage of everything that is on offer.*
>
> Staff 10

Indeed, meaningful learning theory, according to Ausubel (1978; 1968), proposes that it is the student's responsibility to choose whether he or she will opt for rote learning in favour of meaningful learning, or whether they will choose to learn at all. This leaves members of staff with only one variable under their control, namely the organisation and structuring of material and lessons (in this case, practical work lessons), so that they can be learned in such a way that they can be linked with undergraduates' already-known knowledge, as well as promoting interest, so that undergraduates will choose to learn in a meaningful manner (Bretz, 2001). Novak (2010), through his theory of human constructivism, explains that meaningful learning is concerned with being in charge of making meaning out of experiences, and consists of constructive integration of the cognitive (thinking), affective (feeling) and psychomotor (doing) domains.

One of the aims of this study was to understand undergraduates' expectations and experiences related to those three domains of their learning when undertaking practical work lessons, and thus to assess whether practical work in the laboratory offered opportunities for meaningful learning to take place.

In the survey used, adapted from Galloway and Bretz (2015), the cognitive and affective parts of each item were clearly identified. A questionnaire item belonged in the cognitive domain if it only dealt with thinking about concepts, and in the affective if it only dealt with feelings. The cognitive/affective domain was used for items that included both domains of feeling and thinking. Overall, all undergraduates both in Year 1 and Year 2 scored high in all domains, and despite the statistical differences, they produced a median score of 3 on the Likert scale, indicating a positive belief towards meaningful learning both for their expectations and their experiences. Next, each domain is discussed separately, and then they are interlinked, as Novak's model proposes (2010).

Cognitive Domain

The findings indicate that Year 1 undergraduates' expectations regarding the cognitive domain at the beginning of the semester and upon arrival at the university, in terms of what they would do in the laboratory, were not significantly different from the expectations of Year 2 undergraduates (Year 1 pre-test; Year 2 pre-test).

However, expectations were much higher at the beginning of the semester for Year 1 undergraduates than for Year 2 undergraduates whose experience after one semester throughout their second year of studies did not meet their initial expectations (Year 1 pre-test;

Year 2 post-test). Even though Year 2 undergraduates had experienced their first year of practical work lessons, they still had high expectations before the start of their second year (Year 2 pre-test; Year 2 post-test), which, again, went unmet after one semester of studies. Similar findings were reported by Galloway and Bretz (2015a; 2015b; 2015c), wherein General Chemistry undergraduates, corresponding to Year 1 undergraduates in this research, were expected to have, and indeed demonstrated, high expectations at the beginning of their first university semester, due to limited laboratory experience prior to starting their degree (Galloway & Bretz, 2015a). Organic Chemistry undergraduates, corresponding to this study's Year 2 undergraduates, despite their expectations being unmet, still held high expectations regarding learning. The findings support conclusions by Galloway and Bretz (2015a; 2015b; 2015c), that found that undergraduates reset their expectations upon advancing in their studies (in this case, starting their second year at university), despite their unfulfilled expectations. Although Galloway and Bretz (2015c) stated that Organic Chemistry undergraduates lowered their expectations in comparison to those held at the beginning of their General Chemistry course (due to them being unfulfilled earlier), this study found that Year 1 and Year 2 undergraduates' expectations concerning the cognitive domain at the beginning of the semester indicated that there was no substantial difference.

As argued by Bretz (2013), what needs to be clarified to undergraduates, and what needs to shift in this model, is that members of staff – at least in practical work lessons – are not *teaching*, but rather are facilitating, *learning* (Bretz, 2013). As Bretz (2013, p. 281) correctly articulates, this is:

> "A shift from teaching by imposition to teaching by negotiation."

Knowledge cannot be passively passed from members of staff to undergraduates; therefore, undergraduates need to actively participate in the learning process so that they can construct the meaning of their experiments – and, thus, knowledge – in their minds.

Concerning the use of scientific conceptual ideas during practical work, according to the survey responses, undergraduates in Year 1 were initially not expecting to be focused on procedures (instead of concepts) during their upcoming practical work lessons at the beginning of the semester. After one year of experiencing practical work in the laboratory, Year 2 undergraduates, again, demonstrating the aforementioned 'reset' approach, did not have expectations that they would be focused on procedures (instead of concepts). After one semester of practical work for undergraduates in Year 2, they reported that in the end they did indeed focus more on procedures than on concepts, thus demonstrating the aforementioned behavioural adjustment (Galloway & Bretz, 2015c) to reflect their previous experiences. Based on these findings, it is evident that undergraduates did not expect to not use ideas in their practical work lessons; this indicates that the aims of practical work lessons might not have been communicated effectively, as members of staff in the department prioritised procedural training and skill development over learning theory, as a result of practical work, in the laboratory (Table 10). This study's findings reach agreement with those discussed by George-Williams et al. (2018), as more communication regarding the aims of practical work lessons was deemed to be beneficial due to the differences between staff members' perceptions of the curriculum and undergraduates' expectations. For instance, undergraduates in Australia rated the development of transferable skills as the least prominent aim, whereas more than 40% of British undergraduates considered it to be important in preparing them for industry. In fact, among higher-year undergraduates, the aim of enhancement of theoretical understanding decreased as they progressed, while the aim of developing practical skills rating increased. Members of staff in George-Williams et al.'s study (2018) highlighted the importance of both developing laboratory techniques and applying underlying theory in the laboratory – in contrast to this study's findings, where the elucidation of theoretical work to aid comprehension was among the lowest-ranked aims of practical work. Something important to take into consideration is that, as Cann (2014) explains, the growing number of bioscience high school students have increased expectations and limited exposure to practical work before entering higher education, something that makes practical work at university more challenging as undergraduates do not have realistic expectations.

Before starting practical work lessons, both Year 1 and Year 2 undergraduates expected to use their observations to understand the behaviour of humans, animals, plants, cells, atoms and molecules (Tables 31, 24C). Year 2 undergraduates reported that after one semester of practical work they did indeed use their observations for further understanding the organisms or molecules that they were observing. Based on this study's laboratory observations, members of staff helped undergraduates to understand their observations through scaffolding during practical work lessons, which aimed to assist in linking observables with underlying ideas.

Concerning undergraduates' thinking about concepts, engaging with the cognitive domain, all undergraduates in both Year 1 and Year 2 agreed that they understood theory better through practical work (Tables 31, 31C), though Year 2 undergraduates seemed to be more confident in their expectations regarding their conceptual understanding in comparison to their answers at the end of the semester. However, although the percentages in Table 25 show that undergraduates in most laboratory lessons did not demonstrate understanding of underlying theories *during* the practical work lesson, the interviews revealed that they were confident they would better understand after reflecting on their experiences while studying theory at home.

Lastly, all undergraduates confirmed that their expectations were met and that they were indeed able to recall and remember concepts because of practical work (3: Agree) (Tables 31, 33C+). This, however, was not the case for most undergraduates who were asked about their previous lesson in subsequent practical work classes. Perhaps those undergraduates did not have the chance to study during the week. Nevertheless, those undergraduates who attended practical work lessons that were structured with introductory discussions, as well as discussions at the end with members of staff, remembered better in subsequent lessons (Table 25). Taking into consideration the questionnaire items (Table 31) and the fact that undergraduates' expectations were not met (based on this study's findings), it would be useful to propose curricular improvements that can enhance cognitive experiences in the laboratory. However, based on cognitive load theory, practical work in the laboratory should not cognitively engage undergraduates 'more' but 'in the right way', so as to help them use opportunities and integrate the 'thinking domain' to promote meaningful learning. In reality, practical work in the laboratory has to be cognitively unloaded and balanced compared with the information to which undergraduates are being exposed, as both their intrinsic load and extraneous load may be overwhelmed. Based on the literature review findings, undergraduates can, for instance, be introduced to relevant information prior to entering the laboratory in order to prepare them for organising their schemata, so that they can easily process related newly introduced information (EIP, 2016). Kirk and Layman (1996) reported that students' satisfaction with pre-laboratory guidelines enabled them to feel more prepared for their experiment and to better understand concepts. Additionally, pre-laboratory discussions – as previously demonstrated in Table 28, where successful practical work lessons' design features indicated a positive impact on the understanding and remembering of concepts – allowed students to feel more cognitively engaged when working in the laboratory (Davidowitz et al., 2003), and encouraged minds-on behaviour during experiments (Harisson, 2017).

Meaningful learning, as mentioned previously, occurs when in addition to the psychomotor domain or 'doing in the laboratory', the cognitive and affective domains integrate. Here, we need to ask whether the laboratory offers opportunities for cognitive engagement. According to the literature, bioscience practical work should be more engaging and challenging to equip undergraduates with the desired knowledge, skills and conceptual understanding. Adams (2009) noted that laboratory work enthuses and stimulates undergraduates through active learning. Taking into consideration the aims of practical work as ranked by members of staff , the development of theory in the laboratory was not prioritised. Indeed, different instruction forms exist in order to support the goals of the lesson (Johnstone & Al-Shuaili, 2001). The most prominent type of lesson for the laboratories observed in this study was ‘expository’ for Year 1, which slowly progressed towards discovery later on in the year and in Year 2. Domin (1999) explained that an expository-style practical work lesson requires minimal thinking effort. Even though undergraduates’ main goal was to obtain the correct results, there was also not enough time for them to process information from the experiment; this highlights once again the need to take cognitive load theory into consideration. In an expository-style practical work lesson, undergraduates are trained to gain manipulative skills and gather data, which aligns with the goals of the department for Year 1, whereas undergraduates in Year 2 are introduced to exploring and testing hypotheses in a discovery learning model guided by members of staff. This finding agrees with Seery et al.’s curriculum model (2019) for developing experimental design. Undergraduates are progressing throughout the years towards more complex forms of practical work instruction, as they have built their competency by practising scientific procedures and techniques, and have learned to form conclusions on empirical data. Lott (2011) proposed that the transition throughout the levels of enquiry should be done subtly, slowly and gradually, in order to prepare undergraduates accordingly and alleviate stress, instead of using the “jump in to either sink or swim approach” (Lott, 2011, p. 33). Although undergraduates reported that their experiences, albeit positive, did not reflect their high expectations, laboratory observations showed that through a well-structured practical work lesson and with the right support before, during and after the experiment, there is potential for positive results concerning the linking of observables with ideas, as seen in Table 28.

Affective Domain

Initially, it is important to consider that the department of life sciences in which this study was conducted placed the “arouse and maintain interest in the subject” aim, which is directly related to the affective domain, in the middle tier of Kerr’s (1963) list of aims. In contrast, the findings of Kerr (1963) and Boud et al. (1980) reported that members of staff deemed this not to be important. and ranked it in 10th and 9th place respectively. However, Woolnough (1976) and Beatty (1982) emphasised the importance of the affective domain in practical work; this is demonstrated by its inclusion in the undergraduate programme goals of a number of British universities, specifically the “motivation towards learning more science and maintaining interest in the subject" (Durham, 2018; Leicester, 2018; Manchester, 2018; Nottingham, 2018; York, 2018). As Novak (2010 p.5) explains, "while the learner must choose to learn meaningfully, the teacher […], can do much to encourage and facilitate meaningful learning."

The findings from the meaningful learning questionnaire in this study indicate that Year 1 undergraduates' expectations regarding the affective domain at the beginning of the semester and upon arrival at the university, in terms of what they would do in the laboratory, were not significantly different from the expectations of Year 2 undergraduates (Year 1 pre-test; Year 2 pre-test). Undergraduates at the beginning of Year 1 had equally high scores on the affective domain as undergraduates at the end of their semester in Year 2 (Year 1 pre-test; Year 2 post-test). Similarly, there was no difference between experiences and expectations for Year 2 undergraduates (Year 2 pre-test; Year 2 post-test). The median for the affective domain in both pre- and post-questionnaires was 3, indicating a positive belief towards meaningful learning. Contrary to previous research conducted by Galloway and Bretz (2015a; b; c), who reported that undergraduates both in General and Organic Chemistry (equivalent to Year 1 and Year 2 in this study's population) scored lower in all three domains indicating less positive beliefs, this study reveals a consistent and positive belief towards meaningful leaning in both Year 1 and year 2 undergraduates. Furthermore, affective experiences in a longitudinal study (Galloway & Bretz, 2015c) remained constant over time, with equal numbers of undergraduates decreasing or increasing their affective experiences by either adjusting their behaviour or lowering their expectations to adjust to negative experiences. However, Galloway and Bretz (2015c) did not investigate the department's practical work aims, as the affective value might not have been prioritised in the curriculum. Thus, the present findings contribute to a critical understanding of the influence of curriculum design and departmental objectives on undergraduates' affective domain in the context of meaningful learning.

What should be highlighted, as discussed in the study's limitations, is that without Year 1 post-semester questionnaires, this study cannot provide firm conclusions regarding before and after comparisons of undergraduates' experiences concerning meaningful learning in the first year laboratory, although potential negative impact of Year 1 is expected to be seen in Year 2 questionnaires prior to the start of the academic year. Even though there is no significant difference between Year 1 and Year 2 pre-semester questionnaire beliefs on the affective domain of meaningful learning, Abrahams (2011) explains that secondary school students have a false sense of what practical work in science entails, something that can predispose and have an impact on undergraduates expectations prior to starting their university education, as experiments in high school are conceptually undemanding and purely hands-on for simplification purposes and enhancement of the interest in sciences. Indeed, findings from this study confirmed the case as undergraduates held impossible expectations of being autonomous from as early as Year 1 and 2, conducting open-inquiry experiments without guidance and overestimating their abilities in engaging cognitively with scientific ideas whilst doing practical work; something that brought disappointment to them. In contrast to findings from this study, Mistry and Gorman's (2020) reported that even though undergraduates felt confident in their knowledge and experience regarding handling equipment and recording experimental data, they felt unsure on their knowledge of theory and their abilities to design experiments, highlighting the need for such activities to enhance these skills. These findings emphasise the importance of addressing these areas of improvement to better prepare undergraduates for laboratory work and scientific research. Self-efficacy, as highlighted by Cann (2014), plays a significant role in the affective value of practical work. The increasing expectations and limited exposure to practical work among bioscience high school students entering higher education make practical work challenging. However, practical work lessons provide undergraduates with the opportunity to acquire and develop critical skills necessary for their chosen discipline, which theoretical teaching alone cannot adequately provide (Cann, 2014; Dohn et al., 2016). Notably, research has demonstrated a positive correlation between self-efficacy in laboratory work and undergraduates' final exam academic performance, emphasising the importance of self-efficacy in practical work (Dohn et al., 2016).

In an attempt to categorise items into questions measuring positive and negative feelings, the findings from this study show that undergraduates in Year 1 and Year 2, both before and after their experience in the laboratory, scored a median of 3 on the Likert scale, indicating that they did not have any negative feelings about their expectations regarding and experience with practical work. Indeed, their responses to questions whose wording was contrasting (e.g. "I am anxious, confused, frustrated, nervous"; "I am confident, excited, I persevere") were consistent and did not indicate any contradictory statements. Undergraduates were not worried, confused, unsure, nervous, disorganised, worried, frustrated nor intimidated. Instead, based on their survey responses, they experienced moments of insight, were excited, developed confidence, persevered when facing obstacles, were intrigued, and gained experience for their future careers. According to Sharpe (2012), the way in which students express themselves or their behaviour during practical work can provide a means of measuring the affective value of practical work, since it reveals their attitudes. Furthermore, as Amabile et al. (2018) explained, the characteristics of resilience and the willingness to make mistakes are characteristics of intrinsic motivation, as undergraduates are exploring for the sake of knowledge. Similarly, Abrahams (2009) argued that personal interest is concerned with personal preferences, in which a person pays more attention, builds resilience, and engages longer in activities. Moreover, Weber (2003) reported that there is a positive relationship between internal motivation and interest. Based on findings from a study investigating the effects of evolutionary genetics experiment on undergraduates understanding, Miller et al. (2013) established that undergraduates' reported positive improvements in comprehending the nature of science and their attitudes towards biosciences.

The results are encouraging, and indeed challenge staff members' concerns that practical work triggers anxiety amongst undergraduates due to the nature of the lesson. However, this signifies that the department is aware of, recognises, and is taking into consideration the affective value of practical work, as the staff members mentioned actively encouraging their undergraduates in order to make them feel more comfortable, perform better, and start taking the initiative when conducting experiments, given that "practical work is intimidating enough already" (Staff 3). On this note, they appreciate and acknowledge that information that has to be processed during the experiments is overwhelming and that responsibilities, including health and safety, weigh heavily upon them.

According to Maslow's hierarchy of needs, a person's actions directly reflect their attempt to satisfy their needs (Schunk, 2012). Maslow's model presents a pyramid of needs that escalate from basic physiological needs to safety, belonging, esteem, and self-actualisation – needs that must be satisfied from the bottom upwards (Maslow, 2013). Applying this to the laboratory environment observed in this study, safety needs involve structure and support (Maslow, 2013), as was reflected in the results from practical work lessons in which scaffolding and discussions were provided throughout. Undergraduate interviews provided additional evidence supporting the notion that they value support and guidance in their practical work. It was emphasised that it is important for them to have lecturers pointing out relevant information and thus enabling them to identify what they should be focusing on. Another student expressed enjoyment in practical work when there is a clear structure in place, including a guidebook and detailed instructions from staff members, which allows them to obtain sufficient information and know exactly what steps to follow.

Furthermore, belonging can be satisfied by a positive laboratory culture (Steward, 2018); similarly, members of staff acknowledged in their interviews that undergraduates are allowed to talk and work together, which that makes practical work likeable to them. Likewise, and moving up the pyramid of Maslow's needs, esteem can be built from accomplishment; this is reflected in staff members' choice to ensure that undergraduates leave the laboratory with feedback regarding their results in order to know the right answer before going home, so that their reflection processing is stimulated and reinforce their sense of accomplishment. Through these practices, staff members actively contribute to fostering undergraduates' self-esteem by acknowledging their achievements and supporting their journey towards becoming independent learners.

Finally, self-actualisation is triggered by motivating undergraduates with work that is challenging enough to trigger effort, but sufficiently achievable and within learners' zone of proximal development (Taber, 2011), so that it can help them to build skills that push them towards progressing and reaching their potential – in this case, graduating with relevant qualifications conforming to a degree in life sciences.

The findings that reflect behaviours aligning with Maslow's self-actualisation stage can be observed in Figure 20, wherein more than half of the undergraduates who participated in the research (66.4%) wanted to pursue a job in the sciences. This indicates intrinsic motivation (Sansone et al., 2000), which, according to Abrahams (2011), manifests in learners actively pursuing actions related to the field. Similarly to this study's findings, Seymour et al. (2004) reported that undergraduate's enjoyment in practical work was a result of their intrinsic interest in successfully getting into a fulfilling career rather than learning sciences from an educational perspective per se. Indeed, undergraduates, in many responses, stated that the laboratory is the place in which a scientist works and if they realise that they want to work in sciences they learn to enjoy practicals because they will help them reach their career goals.

Although Year 2 undergraduates were reported to be more interested in engaging with extracurricular science-related activities in their free time (60%) than were Year 1 undergraduates (46%), this can be attributed to the fact that first-years are still in the initial stage of developing their experimental skills and competence, as demonstrated in Seery et al.'s model (2019, p. 6), and are not involved in practical work similar to that undertaken by scientists. However, in contrast to Gates et al. (1998) and Humphreys (1997), who claimed that practical work might encourage consideration and interest in pursuing further graduate studies, the relevant questionnaire responses were low for both Year 1 and Year 2. This finding might be attributed to the fact that UK universities focus on long-term goals such as building their students' employability skills (Dearing Education, 1997) and easing their introduction to industry. A possible explanation is that undergraduates embrace such a focus, believing that it is important to develop practical skills that will prepare them for the workforce, as was demonstrated by George-Williams et al. (2018). An increasing number of students enter universities with the primary hope of finding employment (HEA, 2012), and this is reflected in the fact that about 80% of undergraduates are employed while in university (Riggert et al., 2006). Nevertheless, it should not be disregarded that graduate studies have been an unachieved dream for many gifted students, due to tuition fees and financial struggles (Sullivan & Repak, 2018).

As Palmer (2009) explained, educational motivation concerns any action that maintains students' attention towards learning. Although undergraduates' questionnaire and interview responses indicate that they are intrinsically motivated, this does not negate the notion that motivation is fluid and environment-dependent, as it can be affected by extrinsic and intrinsic factors (Hidi, 2000).

For instance, as members of staff explained, assessment plays a major role in attendance and whether undergraduates pay the required attention in the laboratory. According to staff members, if practical work is not assessed, there tends to be lower attendance, as undergraduates have competing priorities and limited time in their degree program. Grades become a priority for them. On the other hand, when practical work is linked to an assignment, undergraduates understand the importance of producing good results and learn skills that they will use in the future. However, if the assignment is removed, undergraduates lose focus and their of engagement decreases.

Indeed, undergraduates confirmed in their interviews that they were concerned about whether their work was assessed to estimate the effort that they had exerted.

Extrinsic motivation, such as grades, is based on something external to the activity of interest or to the person. However, it affects levels of self-determination, as individuals who have enough extrinsic motivation have sufficient levels of motivation to engage with activities that are not intrinsically motivating to them (Sansone et al., 2000). Hidi (2000) further explained that even though someone can be interested in the characteristics of an activity (in this case, practical work), they undertake it because they fulfil their needs by receiving an external reward, i.e. a good grade, rather than acquiring something that would directly motivate them as an activity per se. However, the findings from this study indicate that undergraduates who are invested in pursuing a career in the sciences, though they might dislike some practical work lessons due to a disinterest in the topic, exert effort and maintain their interest in practical work activities – which, by default, constitute the core of a scientist's identity. According to Rodriguez (2018), the environment plays a role in sustaining a student's interest and motivation in science. Studying towards a degree in life sciences, and being guided by members of staff in that field, creates a climate that nurtures a scientist's identity. Since undergraduates, as shown in the findings, have composed their self-views of being the kinds of people who can undertake science (Vincent-Ruz & Schunn, 2018), it means that this scientist identity is being cultivated throughout their learning experiences (Lave & Wenger, 1991). As undergraduates interact with their peers and with members of staff – which Bennet (2005) reported to be appreciated by students – they assimilate scientific ideas and language that impress them (Rodriguez, 2018). As observed in the laboratories, belonging to a community of practice (Wenger, 1998) contributes to the construction of a scientist identity, through interacting with other undergraduates in the laboratory; receiving meaningful recognition from members of staff and themselves (Carlone & Johnson, 2007); as well as thinking, feeling and acting when immersed in a field (meaningful learning; Barton et al., 2008) that motivates them to persevere in making sense of their activities (Jaber & Hammer, 2016). With the scientist identity in mind, when undergraduates endorse this view, they maintain their interest – and, based on Hidi and Renninger's model (2006), a maintained situational interest in multiple practical work lessons leads to, at the least, emerging individual interest and, ideally, well-developed individual interest. Hodson (1996) and Seymour (2004) claimed that practical work gives students the drive to become determined and persistent in finishing their studies.

Nevertheless, as Hidi (2000) contended, if a student who is predisposed to studying science is individually interested in science but attends a class with very low cognitive demand, he or she will neither remain interested nor be motivated.

It is the learners who hold responsibility for developing interest, but it is the relation between individuals and their environment that supports their development (Renninger & Hidi, 2015). Based on Renninger and Hidi's findings, interest was less likely to be triggered when discussion became boring or too difficult to conceptualise. As explained in Vygotsky (2012), meaningful learning will only occur when instruction goes beyond what is already known but is within the reach of existing understanding. This is further illustrated in undergraduates' interviews highlighting the negative impact of lengthy, complex and overwhelming practical tasks as they can cause confusion and disengagement.

On the other hand, according to Renninger and Hidi (2015), students' interest increased when they succeeded in challenging situations, feeling a sense of accomplishment. The effectiveness of instructional conversation as a trigger of interest relies heavily on the quality of scaffolding provided by instruction.

Undergraduates' need for support during the laboratory becomes conflictual, taking into consideration Bennet's (2005) reports that students like being in control of their own learning, and that students' control of an experiment was the reason why they felt motivated (Abrahams, 2009). Students described practical work activities as enjoyable when they had a clear plan that enabled them to lead the investigation without needing assistance (Bennet, 2005). Shepardson and Pizzini (1993) found that problem-solving activities were perceived to be more interesting as students took ownership of their own learning. Furthermore, students' experiences were more positive, despite their difficulty with open-ended tasks (Hodson, 1992). Based on this study's observations, undergraduates could not understand what they were observing without guidance and scaffolding from members of staff; similarly, Millar (2004) explained that students were discouraged when facing difficulties in linking observables with theories. Millar (2004) suggested that students should construct their own knowledge that will give them the autonomy that they need. However, the openness of practical work lessons advances gradually and progressively as students develop their skills and schemata – a finding which aligns with Fay et al.'s (2007) rubric and Seery et al.'s (2019) curriculum model. In fact, according to Seery et al. (2019), as students in Year 2 start becoming more confident and competent in their work, lecturers can make experiments more complex, thus allowing students to progress and level up.

Cognitive/affective Domain

The National Research Council insists that the development of the cognitive and affective domains should not be considered separately (Galloway, 2015d). To better understand how undergraduates integrate their affective and cognitive domains in the laboratory while performing practical work, responses regarding the cognitive and affective domains of the questionnaire were analysed.

> *Human beings are not only remarkable in their acquisition, storage, and use of knowledge; they also manifest complex patterns of feelings or emotions. Feelings, or what psychologists call affect, are always a concomitant of any learning experience and can enhance or impair learning. (Novak, 2010, p. 30*)

The cognitive/affective domain was addressed using questions that included both domains. For the cognitive/affective domain, Year 1 undergraduates had higher expectations than did Year 2 undergraduates (who already had one year of experience in the laboratory). When comparing undergraduates' experiences at the beginning of Year 1 to those of undergraduates at the end of the semester in Year 2, the scores were equally high, indicating that their experiences met their expectations. Lastly, for Year 2 undergraduates, their experiences regarding the cognitive/affective domain were above their initial expectations, which demonstrates the successful integration of the two domains, as thinking and feeling are combined. Undergraduates responded positively to questions, stating that they were learning useful science for their lives, feeling certain about the purpose of procedures, feeling organised, not worrying about acquiring good data and data of good quality, as well as feeling intrigued by instruments and gaining experience for their career. This shows that, at least for Year 2, the design of practical work classes which were mainly focused on procedural work was satisfactory to undergraduates, for reasons that will be subsequently discussed.

The exchange of thoughts, or the negotiation of meanings (Bretz, 2013), between members of staff and undergraduates during scaffolding and introductory and concluding discussions, allowed the integration of the cognitive and affective domains, as demonstrated in the observation below:

> *An example of undergraduates looking to integrate new experiences and learn meaningfully occurred when they were required to determine sex from cells. Undergraduates attempted to explain that amelogenin, acquired from buccal samples, is a gene that differentiates a woman from a man. When they were asked about how sex was determined, they were not so sure about it. After being assisted in completing their polymerase chain reaction (PCR) and gel electrophoresis, which enabled them to distinguish DNA fragments of different lengths, a key piece of knowledge was missing. Once they got the information that the determination of sex was linked to*

> *the length of the gene, they could indeed observe on the agarose gel that two bands indicated a male and a single band indicated a female. Undergraduates were all really excited and they kept showing their peers what they had discovered. Integration of thinking, feeling and doing resulted in undergraduates feeling overwhelmingly happy.*

Experiences resulting in positive feelings can contribute, according to Novak (2010), to meaningful learning. However, as shown in Table 25, undergraduates attending the Molecular Biology practical work lesson did not, in fact, demonstrate any understanding or remembering of their findings, apart from 9% of the class. Although the affective and psychomotor domains were activated, members of staff did not introduce undergraduates to any scientific concepts related to their experiment, either before, during or after the practical work lesson. According to members of staff, undergraduates get a chance to experience all the things that they would otherwise not be able to see in lectures, and they merely need to have fun in the laboratory because they will learn relevant theories in their lectures. According to Novak (2010), knowledge learned by rote is easily forgotten; but the same applies to knowledge which, based on the findings in previous sections, is not adequately linked with observables; and in this case, no discussion was held on the experiment and its underlying concepts.

> *"This misalignment between cognitive and affective expectations decreases opportunities for undergraduates to engage in meaningful learning. This not only brings about negative affective experiences, but also, as a result, can hinder their overall meaningful learning experience."*
>
> *(Galloway & Bretz, 2015 p.2015)*

The absence of scientific concept instruction and the emphasis on the affective and experiential aspect of the practical work lesson alone suggests a missed opportunity for deep learning and meaningful engagement. This critical oversight disregards the fundamental principles of engagement theory, which aligns with meaningful learning theory in highlighting the crucial role of undergraduates' emotional and cognitive investment in the learning process for effective knowledge acquisition and retention. To truly optimise engagement and facilitate meaningful learning, a shift towards collaborative activities emphasising communication becomes very important. Such activities allow undergraduates to learn through connections, defend their ideas and develop their critical thinking skills (Milliszewska & Horwood,2004). Activities apart from project-based should be purposeful so that they can develop a sense of ownership of their learning (Kearsley & Shneiderman,1999). Engagement theory suggests that in the context of practical work, students are more inclined to engage in practical work when they feel like they are included in the science community, when they are confident in their abilities to perform in practical work activities, and when they understand the relevance of practical work in their everyday lives but also to the science community (Kahu,2013).

Consequently, instructors should design educational lab practices that connect with real-world problems to stimulate learning benefits, increase these activities' affective value, and foster undergraduates' understanding of undergraduate biology concepts (Dopico et al., 2013). Bloom's taxonomy and its revision by Anderson et al. (2001) demonstrate that higher cognitive abilities have a significant impact on undergraduates' capacity to analyse, collaborate and take ownership for their learning in the laboratory. It is important to note that these higher-level cognitive processes can be gained through a spiral curriculum approach that incorporates and reinforces cognitive skills throughout undergraduates' studies and can better prepare them for scientific inquiry and problem solving. This is something that has been demonstrated in Seery's rubric (2018) and has been evident through the aims members of staff set while designing their modules in this study.

What is Practical Work For, Then?

A proposed model for learning at Level 2 with practical work:
Through the lens of educational learning theories and cognitive neuroscience

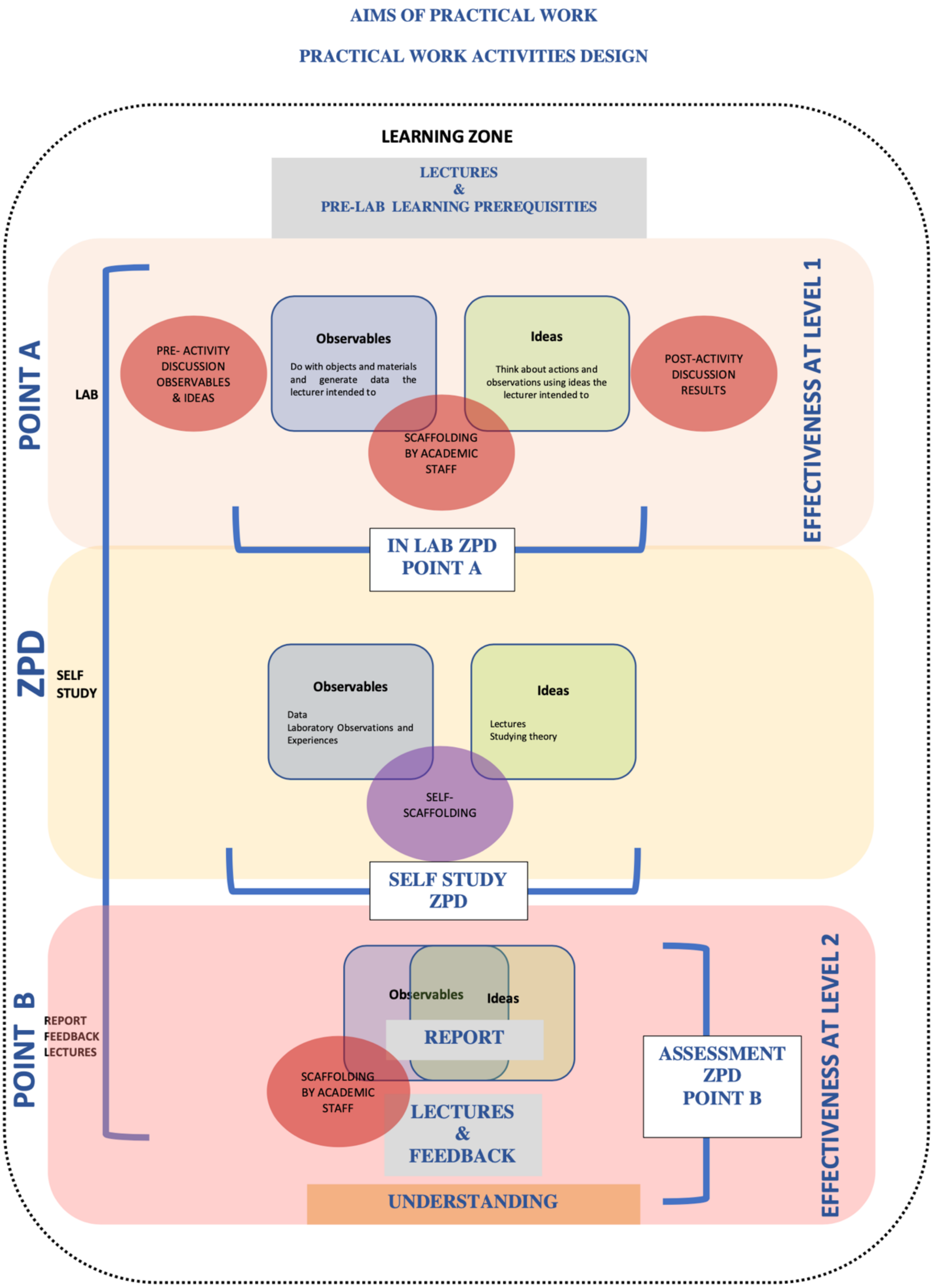
After taking into consideration the research findings from a recent study exploring the learning of science without face-to-face practical work due to the lockdown restrictions imposed by the Covid-19 pandemic (Kelley, 2021), along with this study's findings from laboratory observations and interviews with both undergraduates and members of staff, a model was constructed that proposed a potential method of making practical work more effective for learning. "No man is an island, and neither is practical work" (Constantinou, 2022, p. 1). Although Abrahams and Millar (2008) claimed that when effectiveness at Level 1:o becomes the sole aim of practical work the learning value is significantly limited, the benefits should not be depreciated, as practical work should be seen as a tool in the process of learning science, and not as an independent entity with which undergraduates directly develop their knowledge. Practical work is serving as a teaching medium (rather than as a standalone practice) for promoting theoretical understanding of the sciences. Thus, practical work should be regarded as an activity which is part of a bigger learning zone. Initially, learning begins as soon as undergraduates register for studying towards a degree, in which departments set learning goals for the module curriculum. Each module, not only by itself but also as one of the constituent parts of the degree, becomes an active learning zone, as depicted in Figure 24.

The model proposed follows the constructivist path and focuses its attention towards learners and creating collaborative, interactive learning environments, as part of a social learning space in which undergraduates interact with peers and members of staff (Alanazi, 2016). The Vygotskian zone of proximal development (ZPD) (Vygotsky, 1978) plays an important role in the model, denoting the distance that undergraduates undergo through scaffolding and peer discussion (Schunk, 2012) in order to achieve, with the help of experts, the desired learning goal, and thereby move beyond their current level of learning capability. The model proposes that inside the learning zone (Figure 23), different small- and large-scale zones of active proximal development can be found that aim to lead undergraduates from Point A (i.e. that of a novice), to Point B (that of an expert). Dewey, the founder of the constructivist approach, proposed a learner-centred instruction, which was previously referred to in the practical work lessons of this study; this requires collaboration between undergraduates and members of staff in an active learning process framework (Richardson, 2007). In the model, a proposed rapprochement between Vygotskian socio-constructivism and Piagetian cognitive constructivism will be attempted, with both contributing to constructivist theory.

This model was created, as previously mentioned, while taking into consideration the findings from this study after extensive laboratory observations, as well as interviews with members of staff and undergraduates. The author suggests that the effectiveness of practical work can be improved and enhanced by bearing in mind factors, explained through cognitive neuroscience and educational learning theories, that can contribute to undergraduates' learning. It is important to redefine the purpose that practical work serves in the learning process, as well as its correct placing in space and time. All members of staff agreed that it is impossible to control how undergraduates choose to study at university. The researcher believes that a well-structured curriculum can provide them with different opportunities, of which it is undergraduates' choice to take advantage of.

Figure 23

Proposed model for the conduct of practical work, implementing theoretical models proposed by Vygotsky (1978) and the zone of proximal development, Millar et al. (1999) and the effectiveness of practical work at Levels 1 and 2, and Tiberghien (2000) and the domain of observables and the domain of ideas



Large-scale ZPD – From Laboratory to Assessment

Initially, the biggest zone of proximal development begins vertically at Point A (being the laboratory space in which practical work is conducted) and ends at Point B (when the synthesis of experiences and scientific ideas is transferred to paper as part of an assessment).

Point A – In-laboratory ZPD – Effectiveness at Level 1

The laboratory is regarded as the starting point at which members of staff are suggested to focus on effectiveness at Level 1 (Millar et al., 1999) and in both the domain of observables and the domain of ideas (Tiberghien, 2000). Pre-laboratory activities as prerequisites, regardless of whether a lecture precedes the practical work lesson or not, are important for providing a theoretical background before entering the laboratory (Hodson, 1996). This allows undergraduates to follow the Popperian methodology (Hattie & Donoghue, 2018) and form a hypothesis upon entering the laboratory, by means of the hypothetico-deductive model – in order to accept or reject it by the end of their practical work lesson. Pre-laboratory activities could include argumentation construction (Chen & She, 2012), which could potentially be conducted online using technology, as proposed by Kelley (2021). Modern laboratories have been reported to starting to becoming hybrid, physical and virtual as universities are now embedding virtual laboratories to enhance undergraduates' conceptual understanding (Al-Khalaf, 2021). Learning through 'exploring' or questioning ideas allows learners to consider and critically decide whether to accept or refute them. Thus, undergraduates can have a pre-argumentation question in their mind before practical experiments.

After undertaking their experiment, post-argumentation questions will have to be answered. This method allows undergraduates to develop self-hypotheses in their mind and later decide through practical work whether or not to continue supporting it.Such argumentation allows undergraduates to use the scientific method of investigation by enquiring and predicting, which provides the opportunity to either acquire new knowledge when proven wrong, or to verify the initial idea. In addition, writing their arguments and discussing them online allows undergraduates to exchange ideas and arguments more efficiently than exchanging ideas verbally in a traditional laboratory environment, wherein information needs to be processed in a limited time.

Upon entering the laboratory, pre-activity discussion on observables and ideas is recommended, as the findings from this study showed that this was beneficial for undergraduates by explaining the purpose of the experiment, and providing a theoretical background with which they could mentally engage while being hands-on. This is marked as Point A of the in-laboratory zone of proximal development. During the experiment, undergraduates are expected to do with objects and materials, and generate data, as the lecturer intends them to do; as well as to think about actions and observations by using ideas that staff members introduced through pre-laboratory activities, introductions and scaffolding. Lastly, undergraduates reach Point B of the in-laboratory zone of proximal development when a post-activity discussion on the findings and results is provided by members of staff, who will explain what they saw, and how observations are related to the relevant scientific theories that were initially introduced before the experiment and scaffolded during the lesson.

Piaget proposed that mind structures which represent reflections of our surroundings, i.e. schemata, help us to interpret our environment (Woolfolk, 2011). Schemata develop and become organised upon a person's cognitive maturation, to facilitate a more logical complex and sophisticated way of thinking (Woolfolk, 2011). Internal cognitive stability (Schunk, 2012) is sought through learning (Schunk, 2012); therefore, when undergraduates experiences something that does not conform the existing schema, perturbation arises. When cognitive conflict arises, equilibration and the restoration of balance are desired. Since learners are not a tabula rasa when they embark on their degree journey, they need to have assimilated and internalised scientifically valid concepts before entering the laboratory, so as to reduce the cognitive load that can potentially overwhelm them due to the novelty of the experiments and the unexpected findings. When undergraduates study the relevant material before a practical work lesson, their mind will be prepared to accept the guidance through the explicit linking of information that will already be, in a sense, familiar to them; and either that will be assimilated in an already-existing schema (Woolfolk, 2011; Schunk, 2012), or a new schema will be created that will match the external reality through the process of accommodation (Snowmanm, 2011). Once undergraduates become familiar with a schema after studying the relevant content, members of staff can activate this knowledge when they expose them to the relevant content in the laboratory to which the schema is applicable (Schunk, 2012).

If cognitive conflict is overburdening undergraduates' memory when they face something unfamiliar in the laboratory that they have not previously studied, they can sometimes ignore accommodation and assimilation; this can distort information so as to make it align with previously assimilated material (i.e. misconceptions), to fit their already-existing schemata (Woolfolk, 2011). Working memory has to be vacant, because a heavy cognitive demand will affect the accumulation of knowledge in long-term memory (Sweller, 1999).

Discussions before and after practical work activities ensure that potential cognitive conflict does not overwhelm the brain and, therefore, hinder learning. Undergraduates are assisted in linking the domain of observables with the domain of ideas, and start equilibrating from an external environment to an inner mental-process manner in a ZPD. Development appears inter-psychologically through interacting with peers and constructing knowledge through language, which is a crucial tool in Vygotsky's theory (Waring, 2006; Woolfolk, 2011), and intra-psychologically when experiences are internalised (Woolfolk, 2011). According to Vygotsky, learning helps intellectual development through language-supported guidance from more knowledgeable others. Undergraduates should not rediscover already-available knowledge in scientific culture, as this is not about reinventing the wheel, but rather about being guided by members of staff, i.e. experts, in order to learn it (Woolfolk, 2011).

It is crucial to remember that human cognitive architecture is of vital importance when performing practical work, as interactions between working and long-term memory, in conjunction with cognitive processes, support learning (Atkinson & Shiffrin, 1968) in the laboratory classroom. When processing novel experiences, that information is limited in duration and capacity in the brain. A large amount of the information is stored in working memory is lost within 30 seconds if not rehearsed (Peterson & Peterson, 1959). For this reason, words, concepts and ideas which are processed in short-term memory and retained for a limited time need to be linked to something visual (such as procedural knowledge) so as to become solidified, as images go directly into long-term memory (Burmak, 2002). Visuals help undergraduates to make sense out of content, thus enhancing opportunities for recollecting their experience (Schunk, 2012). This is in line with undergraduates' claims during interviews, regarding the benefits of 'visualising theory':

> *This reinforces theory, especially if you are a visual person [who] can see theory in front of you.*

Working memory is fragile in the sense that information, if not enhanced either through scaffolding by members of staff or by studying further, decays and becomes lost. The amount of information in working memory can be increased if learned in a meaningful manner (Schunk, 2012). Repeating information in working memory can improve recall (Baddeley, 2001; Rundus, 1971; Rundus & Atkinson, 1970); this finding has already been confirmed through this study's observations, and interviews with both undergraduates and members of staff confirmed that “there has to be constant reinforcement”. The more an idea is encountered, the stronger its representation in memory (Schunk, 2012).

Repeated exposure to information, as well as expanding that information, as explained by the process of elaboration – which occurs through exposure to sources prior to the practical work lesson, lectures, laboratory pre- and post-experiment dialogic approaches, and scaffolding during experiencing ‘doing with observables and material’ – visually helps undergraduates to practise and access the relevant information multiple times in multiple different ways, through a combination of teaching methods (Hobbis, 2018); something fitting the notion of partial representations as explained in neuroconstructivism (Mareschal et al., 2007). According to Schunk (2012), meaningfulness contributes to improved retrieval as this activates information in the long term memory that would otherwise be lost unless repeatedly rehearsed and established in long-term memory. By keeping information active in the working memory through the incorporation of the cognitive, psychomotor and affective domain (Galloway and Bretz, 2015), the formation of networks through elaboration increases the likelihood that the information will be permanently stored in long term memory (Schunk,2012). Undergraduates who use what they have learned in writing essays or participating in discussions, learn how to use their learning and the knowledge acquired becomes ‘active’ and more memorable (Kugel, 1993).

Regarding the Zone of Proximal Development

The Piagetian accommodation and assimilation concepts are closely associated with Vygotskian concepts. Guidance from members of staff while in the ZPD provides undergraduates with mental supplies that lead to cognitive development. New learning concepts during practical work need to be close to information studied previously, so that conceptual topics are already assimilated upon their arrival in the laboratory, and to allow accommodation to take place, bridging the two (Van Geert, 1998). Dialectic teaching, influenced by the philosopher Hegel, can provide undergraduates with information that will challenge thoughts between what is known (thesis) and what is opposing prior ideas (antithesis), and can assist in reaching equilibration by resolving old and new concepts (synthesis) (Van Geert, 1998; Mueller, 1958; Schunk, 2012;). The cognitive system is continuously updated upon new experiences in the ZPD, and knowledge achieved (or Point B in the ZPD) develops further as schemata expand and become more complex, through the gradual formation of various overlapping representations of the environment (Hobbis, 2018). It is important to remember that for a ZPD to occur, cognitive conflict needs to take place so that accommodation and assimilation can happen. Practical work should be staged in such a way as to teach undergraduates how to process novel information and bridge observables with ideas, by having members of staff collectively acting as an external artificial brain.

Intermediate Facilitator – Self-study ZPD

In this study's findings, many undergraduates reported that practical work helps them to remember, so that when they go home, they can link what they have done with the relevant theories:

> *I see things, I interact and I remember. I take notes and when I go home, I read relevant theory and tie things up.*

At this point, undergraduates should work on their own in order to reflect on and link their experience with ideas that were presented in lectures, or learned through studying from books and articles. Experiences that occur closely in time are more likely to be linked in memory, so that when one experience is remembered through reflecting on the experiment in the laboratory, for instance, the other (i.e. information from self-studying) is activated (Baddeley, 1998). Human memory is "content addressable" (Schunk, 2012, p. 184); thus, knowing visually what is being looked for will most probably allow the recalling of that information later. Undergraduates who have been trained in developing their metacognitive skills through scaffolding in cases such as questioning, researching and evaluating information, can become better self-learners (Dawson, 2008).

Self-scaffolding is the concept of thinking about thinking (Dawson, 2008; Bichard, 2005); and in contrast to scaffolding by experts (such as members of staff), undergraduates' minds communicate directly with their cognition through self-scaffolding (Holton, 2006). Hence, self-scaffolding is a sophisticated learning mechanism that helps undergraduates to advance throughout their studies and handle cognitive challenges (Bosanquet et al., 2014). As Taber (2011) explains, metacognitive awareness or the development of study skills, should have a high priority as an educational aim as learners will be able to build on their learning. Pre- constructed self-knowledge that has already been assimilated can be used as a resource for new construction in the framework of self-scaffolding (Bichard, 2005). Even though undergraduates at this point are developing as independent learners, requesting guidance is still a form of self-scaffolding, as they are conscious of cognitive gaps that need to be filled (Bosanquet, 2014). Through self-scaffolding, undergraduates undergo their own zone of proximal development through self-studying. In this process, previously assimilated knowledge can be used as an individual expert that can assist the now-challenged self through previously acquired experiences in the laboratory (Constantinou,2016), which are recalled through reflection – so as to reach a new developed cognitive state. Implementing Vygotskian and Piagetian concepts together can help undergraduates to refine their schemata and progress towards intellectual development more quickly. Both theories can be merged for a better understanding of undergraduates' way of thinking and, consequently, better instruction, by fostering critical thinking (rather than rote learning) (Constantinou,2016). Kolb's model (1984) describes learning as follows:

> The process whereby knowledge is created through the transformation of experience. (Mughal & Zafar, 2011, p. 29)

Through practical work lessons, the learning process gives undergraduates the opportunity to attend those 'experiences' that will be later linked to scientific concepts through other teaching and learning modalities.

Point B – Assessment ZPD – Effectiveness at Level 2

When reaching the final stage of the vertical large-scale ZPD, i.e. Point B, undergraduates are expected to synthesise their acquired knowledge from their laboratory experience with ideas learned through self-studying and lectures. Observables and ideas are merged on paper during the write-up of a laboratory report; members of staff can assess whether undergraduates are able to recall what they have done with objects or materials observed during practical work, while they also demonstrate an understanding of the ideas that the task was designed to help them to learn. Whilst the laboratory report is the starting point (Point A) in the assessment ZPD, it is through lectures and feedback received on the assignment that the learning process is completed and understanding is achieved at Point B, if the effort is made by undergraduates. It is during the assessment stage that effectiveness at Level 2 should be examined. Mathews and McKenna (2005) found insufficient evidence that a post-laboratory report proves a conceptual understanding of theories learned while performing practical work, possibly in contrast to Walsh et al. (2010); this issue can be examined in future research. However, the acquisition of theoretical knowledge is merely a result of information synthesis through, for instance, writing a report. Indeed, as Taber (2011) explains it has been challenging to understand the assessment of learners through examinations as it is questionable whether marks should be awarded with the criterion that the learner memorised a topic or understand whether the undergraduates' own interpretation sufficiently reflect the canonical meaning of the concept tested. During the write-up of a report, the reflective processing of a performance during a practical work lesson – along with learned theories through self-studying, attendance at lectures, and discussions with more knowledgeable others – can contribute to building knowledge. Whilst the obtainment of skills can be observed *in vestigum* through undergraduates' responses and reactions in the laboratory, the understanding of knowledge should not be expected to develop as a result of practical work activities. Rather, the presentation of ideas through discussion or as part of an assignment allows undergraduates to bridge the domain of ideas and the domain of observables, and build a conceptual understanding.

Lastly, through the multiple zones of proximal development developed within the learning zone of a departmental module, the longest ZPD begins in Year 1 and ends in Year 3. By slowly building enquiry and technical skills, undergraduates can move to higher levels of enquiry and climb the ladder. Evidence of climbing the ladder lies in assessment.

It should be noted that pre-learning and post-learning activities, including blended learning, can be accomplished through a flipped classroom model that combines in-laboratory activities along with online learning through, for example, through discussion forums. In this way, quality time in the laboratory can be spent in guiding the linking of observables with ideas whilst online time can encourage undergraduates to interact with each other as well as with members of staff to elaborate on learned information so as to reinforce the information learned.

Practical Work as a Culture

Practical work should not be regarded as merely another activity designed in an attempt to promote skill development and the promotion of conceptual ideas. Vygotsky claimed that an individual’s mind is shaped through exposure to their socially and culturally situated environment, as the community is key to making meaning of one’s surroundings (Vygotsky, 1978). Practical work is not only important because undergraduates develop their skills, nor should it be pinned to the potential development of conceptual understanding as a standalone activity. Practical work should be regarded as a ‘ritual of initiation’ into scientific culture, as undergraduates develop a greater awareness of the scientific community, despite the fact that expository-style practical work does not represent the true nature of scientific research. Exposure to methodologies, language, and, in general, the exact environment in which a scientist works, is an indirect product of the zone of proximal development, which should not be narrowly conceived as merely a zone in which an expert provides learning opportunities to an undergraduate, although this is part of the process (Schunk, 2012). Vygotsky found that the laboratory scientific culture impacted learning, in the sense that undergraduates’ cognitive development became affected by beliefs, morals and attitudes modelled in the culture in which they were working; as a result, this culture began to affect undergraduates’ behaviour (Kurt, 2020):

> “It is a cycle; at the same time that the culture is influencing an individual, that individual is in turn creating culture.” (Kurt, 2020, para. 1)

Covid-19 pandemic calls for a truce: Time to end the debate

For many decades, the purpose of practical work in the laboratory swung in a pendulum-like manner, from verification of scientific facts through demonstrations, to Armstrong and the heuristic approach (Abrahams, 2011; Armstrong, 1903); then back to the development of conceptual understanding (Thompson, 1918), and once again, to the promotion of acquisition of physical transferable skills, after publication of the Norwood Report in 1943. Furthermore, the resurgence of the heuristic approach after Bruner’s work in 1961 gave rise to discovery-based courses, where pupils were viewed as scientists who had to do science in order to understand science (Abrahams, 2011). However, doubts arose about claims that understanding is a side effect of doing science, since conceptual learning expectations through discovery learning were excessive and unrealistic (Abrahams, 2011; Bennett, 2003; Driver, 1983; Hodson, 1992, Lawarowitz & Tamir, 1994).

During the 1980s, practical work was regarded as an activity for promoting the processes of science, rather than its concepts, through the Warwick Process Science (Abrahams, 2011; Screen, 1986). Again, by the 1980s and 1990s, the pendulum had swung back, due to growing arguments on the fact that science processes cannot be content- independent, as content will be regarded as unimportant (Abrahams, 2011; Hodson, 1991; Millar, 1989). Despite the laboratory's long-standing place in the teaching of sciences, there is still dissatisfaction about its contribution to learning, and therefore, demands for its reconsideration as an approach are occasionally raised (Seery et al., 2018). Discussions on the purpose of practical work, "despite 200 years [and more] of debate" (Millar, 1987, p. 113), have eventually morphed into a Newton's cradle, swinging almost indefinitely between ideologies and approaches. However, as Schulz (2021) explains:

> *It is impossible to have an ideal Newton's cradle, because one force will always conspire to slow things to stop: friction. Friction robs the system of energy, slowly bringing the balls to a standstill. (para. 35)*

After decades of practical work being a subject of debate, due to high costs, increased hazard awareness, and considerations on how to rightly prepare STEM students for the industry (Kelley, 2021), such friction brought the science education community to the above-mentioned standstill; a moment of truth where research-based evidence was needed to answer the critical question: "Does it have to be hands-on?". Coincidentally published just before the Covid-19 pandemic, Bretz's (2019) question echoes and aptly applies to this study's goal regarding the purpose of practical work in life sciences:

> *What evidence does your department have that the significant investment of space, time, personnel, and resources is essential for your students to learn chemistry? What arguments and data would your department amass to defend laboratory instruction if your university administration decided that virtual laboratories and simulations would be a far less expensive pedagogy that does not compromise student learning? Chemists can no longer afford to believe that the importance of teaching laboratories is a*

> *truth we hold to be self-evident. As scientists we must support our research claims with evidence. Our claims about student learning require this same standard. (p. 194)*

Considering that examinations are mainly based on lectures, what is questionable is whether laboratory work is that essential that if it disappeared from the curriculum it would affect undergraduates' performance towards their degree.

The Covid-19 pandemic's restrictions, which forced most of the undergraduate population to temporarily adopt remote learning and prevented access to the laboratory, has provided the science education community with a real-life scenario of teaching sciences without practical work, and its effects on the learning process.

It has become evident that the laboratory, which was regarded as "the very essence of the science learning process" (Abrahams, 2011, p. 9), has now been reconsidered, along with the purpose that it serves in teaching.

As a result, even more now than before considering the new status quo in a nearly post-pandemic world, laboratory learning goals should be revisited and redetermined so as to understand which activities can be fostered through face to face experiences and which through other teaching modalities.
Life sciences require a hands on approach when manipulating equipment and objects while also a minds on approach when making observations, analysing and understanding phenomena, thus one could consider practical work essential at university.

Laboratory time should be prioritised by having undergraduates training hands-on and developing their skills and working towards accomplishing goals related to Millar et al.'s (1999) Effectiveness at Level 1, in which practical work, based on this study's findings, was deemed as most successful. Development of conceptual ideas and non-technical competencies can be shifted to out-of laboratory teaching spaces. According to Kelley (2021) we should consider boosting learning in the laboratory by incorporating complementary activities that were successful as part of remote teaching so that laboratory time will be solely used for what we now know, based on this study's findings to work, as effective - Effectiveness at Level 1. Effectiveness at Level 2 should be enhanced through the incorporation of the right constructivism-led and neuroscience based mechanisms ,discussed above, in the laboratory thus initiating the learning process of conceptual knowledge through the long vertical Zone of Proximal development depicted in Figure 23. As a result, this will contribute to equipping undergraduates with the right conceptual background and manipulative skills that will drive them towards crossing the longitudinal ZPD beginning in Year 1 and ending in Year 3 when the degree ends.

To summarise, in a post-pandemic world, laboratory learning goals should be revisited and redetermined, in order to understand which activities can be fostered through face-to-face experiences and which through other teaching modalities. Laboratory time should be prioritised to ensure that undergraduates are physically training, developing their skills, and working towards accomplishing goals related to Millar et al.'s (1999) effectiveness at Level 1 – among which, practical work, based on this study's findings, was deemed to be most successful. The development of conceptual ideas and non-technical competencies can also be shifted to out-of-laboratory teaching spaces. According to Kelley (2021), we should consider boosting learning in the laboratory by incorporating complementary activities that were successful as part of remote teaching, so that laboratory time will be solely used for what we now know works effectively, based on this study's findings – i.e. to ensure effectiveness at Level 1. Effectiveness at Level 2 should be enhanced through incorporation of the appropriate constructivism-led and neuroscience-based mechanisms, as discussed above, in the laboratory; this will initiate the learning process of conceptual knowledge through the long vertical zone of proximal development (depicted in Figure 23). As a result, undergraduates will be equipped with the right conceptual background and manipulative skills that will carry them across the longitudinal ZPD, beginning in Year 1 and ending in Year 3 (when the degree ends).

Chapter 6 Conclusion

Chapter 6 draws together the study’s key findings through the lens of the three key research questions used and expanding on how the study has contributed to knowledge in the field of science education and particularly university practical work in life sciences. Further to this, methodological limitations are identified and discussed as well as implications for further research, life science university departments, members of staff and undergraduates.

Overview

Research Findings and contribution to knowledge

This research study posed three research questions concerning the effectiveness of practical work in life sciences at a university in England.

1. What are the aims of practical work amongst a small representative sample of lecturers in the department of life sciences at the chosen university?
2. Are practical tasks effective in enabling undergraduates do or/and learn what intended? If yes, when?
3. Does practical work contribute towards meaningful learning? If so to what extend the affective value contributes to that meaningful learning and what is it for?

This study emphasised the need to understand how practical work is practised in the laboratory, and how it is experienced by undergraduates and members of staff with regard to its effectiveness as a pedagogical practice in life sciences. As Casey (2007) explained, understanding how practical work is experienced and how it is conducted allows us to clarify the purpose that practical work lessons serve.

In answer to the first research question, which is the standard that the ‘ effectiveness’ of practical work was measured against, members of staff, either pre-planned or unintentionally, determined the aims their laboratory lessons focused on when designing them and consequently the teaching approaches used. Findings suggested that undergraduates are progressively trained following a plan ranging from Year 1 and exposure to expository models of low level inquiry, to Year 3 and open-inquiry practical work . Year 1 focused mainly on hands-on processes like adopting simple scientific methods of thought, experiencing physical phenomena in the laboratory and developing manipulative skills. Year 2 slowly implemented minds-on processes as amongst the top aims were the training in problem solving, applying scientific methods of thought and encouraging accurate observation and careful recording, aims which were also prioritised in Year 3 complementary to a minds-on and hands-on approach of finding facts by investigation and arriving at principles. Interestingly, aims concerning the development of skills and a scientific attitude which were prioritised in Year 1 became less significant as undergraduates progressed to more senior years , Year 2 being a transitional year, where minds-on approaches were gradually implemented assuming adoption and application of the already acquired skills from earlier Years ,now moving to the bottom of the Kerr's (1963) rank list of 10 aims. Members of staff perceived aims were reflected in the learning objectives of laboratory lessons observed for both Year 1 and Year 2 as for the former undergraduates were mainly focused in getting trained on using scientific equipment and following unfamiliar practical procedures whereas for the latter undergraduates were mainly introduced to already familiar techniques, equipment and procedures whilst being introduced to higher order and more demanding approaches of scientific enquiry relating observations to conceptual ideas.

Even though open-inquiry practical work approaches better reflected Year 3 individual research projects and despite the fact that members of staff did not regard the elucidation of theoretical work through practical work as important, in Year 2, the analysis; presentation of data; development of evidence-based conclusions and assessment of their validity was prominent and assessed in laboratory reports. Despite the fact that undergraduates were requested to suggest explanations for their data, the average importance of scientific ideas for the successful completion of laboratory practical tasks for both Year 1 and 2 was unimportant, indicating that conceptual knowledge acquisition can take place *after* practical work whilst throughout experiments in the laboratory theoretical support to enhance understanding was provided by members of staff.

In answer to the second research question, the effectiveness of practical work was related to the intentions of members of staff and was investigated in two levels and domains, learning and doing, observables and ideas, respectively. A careful comparison of the structural characteristics of practical work lessons during observations gave insights into patterns that proved to be beneficial in promoting better conceptual development and recalling of observations in the laboratory. Based on laboratory observations the majority of practical work lessons were focused on practising laboratory skills and scientific processes, something which was attributed to members of staff' vision for preparing undergraduates for future employment in the industry. Findings indicated that practical work was effective in the domain of observables at Level 1 as undergraduates could indeed demonstrate abilities in using equipment, following procedures and carrying experiments correctly the way members of staff intended them to do so, but only after being explicitly guided and supported. The practical work lesson was designed in such a way and followed an expository approach in order for members of staff to have teaching space and devote enough time in assisting undergraduates. Most importantly, 'repetition' was a key finding as members of staff achieved their teaching goals through exposing undergraduates repeatedly and systematically to procedures and equipment so as to master their skills by automatising them; something that members of staff believed that could shift undergraduates' focus towards observations and careful data collection. In consistency with findings from other studies, in most laboratories observed undergraduates did not have a better understanding of underlying conceptual ideals related to their experiments. However, this does not, at least not necessarily, indicate ineffectiveness of practical work at that level as this was, to some extend, expected. This is because conceptual development was not intended by members of staff when designing the lesson and the importance of scientific ideas to carry out the activities well was ranked relatively low for all three years.

In contrast to that, some findings showed that laboratory lessons in which conceptual understanding and recalling were demonstrated by 50–88% and 50–75% of undergraduates, respectively, were structured in such a way that verbal discussion on the experiment's purpose and its underpinning scientific ideas was provided at the beginning of the lesson, and a confirmation of observations at the end; this factor might have contributed to successful subsequent recalling of information. Moreover, although practical work lessons for the majority of core modules usually consisted of approximately 100 undergraduates, the aforementioned 4 out of 18 practical work lessons that showed evidence of successful understanding and recalling of ideas consisted of 40–52 undergraduates in total.

Interestingly, as undergraduates explained, successful recalling might be attributed to engagement in laboratory discussions, as well as complementary out-of-laboratory learning opportunities (lectures, self-studying) that aid in reflecting practical work experience, and thereby gaining a deeper understanding. The findings show that practical work was effective because the outcome was in line with what members of staff intended undergraduates to achieve: developing manipulative skills and promoting simple scientific methods of thought.

Even though the importance of scientific ideas was not very important neither the development of scientific knowledge for both Year 1 and Year 2, this shows expectations which did not have to be fulfilled *in* the laboratory*,* and *while* doing practical work. Indeed, findings show less evidence that undergraduates could think about their observations using underlying ideas, *on their own,* something supported in literature as ideas do not directly develop from experiments. Engagement with theoretical concepts through findings facts and arriving at principles was only prioritised in Year 3 when undergraduates would have experience and develop expertise through refined schemata so as to think and apply material learned in a scientific way. Instead, in Year 1 and 2, this internal scientific mental process expected from undergraduates in Year 3, was done by members of staff through scaffolding. Furthermore, interviews with undergraduates showed that they were confident in stating that practical work was the reason they could remember what they had learned in the laboratory and thus be able to use those experiences and link the two domains while studying on their own. These experiments, they argue, had given them a better understanding of the theory, something which corresponds to one of the highest ranked aims for Year 1, ‘ Making physical phenomena more real through actual experience’. Despite their claims, findings showed that in all lessons observed but the four distinguished, only less than half of undergraduates could recall practical work findings and related concepts in follow-up sessions with most remembering scattered information.

In general, findings indicated that practical work is effective in developing manipulative skills and promoting scientific thinking, both regarded by members of staff as important. Hence , undergraduates did what they were expected to do and saw what they were intended to see, when appropriately guided. This indicates that when practical lessons are clearly designed and are aims-oriented then the practical activities are fit for their purpose. The findings also indicated that members of staff see practical work in life science degrees more as training sessions which would help undergraduates to advance their laboratory experience and skills needed, on one hand, to complete their undergraduate studies and, on the other, for a career in a science-related job. However, observations from this study revealed that practical work is not just an activity but a learning zone whose effects expand beyond the laboratory setting. Practical work *per se* might not be a direct means of learning scientific ideas but it can be an important part of a collective learning process, or as Millar (1991 p.1) phrases it “a means to an end”, comprising of a combination of different learning strategies that need to co-exist so as to bring about desired results.

In answer to the third research question and with regard to the contribution of practical work lessons towards opportunities for meaningful learning left members of staff with only one variable under their control; the structuring of practical work lessons. As Ausubel (1978) supports, it is up to the undergraduates to choose whether they will decide to go for rote learning or meaningful learning. Concerning the cognitive domain, findings indicate that Year 1 undergraduates' expectations at the beginning of their first year and prior to entering the laboratory and with limited laboratory experience were not significantly different from those of Year 2 undergraduates, albeit higher. Year 2 undergraduates' experience after one semester of conducting practical work, did not meet their initial expectations. However, albeit having their expectations go unmet, undergraduates demonstrated a 'reset phase' and still held high expectations at the beginning of the year, which again went unmet. In fact, undergraduates in Year 1 expected being more focused on concepts instead of procedures whilst Year 2 undergraduates reported that in the end they did indeed focus more on procedures than concepts, adjusting their behaviour to meet their experiences. It was indicated, and confirmed by other studies, that the aims of practical work lessons were not communicated effectively as members of staff in the department prioritised procedural training and skill development over theoretical learning from the beginning anyway. However, Year 2 undergraduates reported that after one semester of practical work they did indeed use their observations for further understanding what they were observing, as they were expecting. This was actualised with the help of members of staff who assisted undergraduates understand their observations through scaffolding throughout their experiments, aiming to link observables with underlying ideas. Even though undergraduates claimed that they understood theory better through practical work, this was not demonstrated by the overall percentages from laboratory observations, but perhaps demonstration of understanding was not expected to happen *during* practical work lessons. Nevertheless, undergraduates were confident that they would understand better after reflecting on their experiences during self-study. Again, despite undergraduates' claims that they recalled and remembered concepts because of practical work, percentages from laboratory observations did not demonstrate the case. However, undergraduates who attended practical work lessons structured with introductory, in-laboratory and end of practical work lesson discussions demonstrated better recollection in subsequent lessons. On that note, curricular improvements to enhance cognitive experiences in the laboratory are suggested based on findings of this study as practical work should not cognitively engage undergraduates ' more ' , as intrinsic and extraneous cognitive overload from 'crammed' discussions and guiding material hinders learning. Instead practical work should cognitive engage undergraduates ‘ in the right way’ , with supportive pre-laboratory activities that will allow enough cognitive processing ‘ space’ and pre-prepared schemata that can be modified with in-laboratory guidance from members of staff.

With regard to the affective value, and although this was not directly assessed, members of staff argued that arousing and maintaining interest in the subject was a fairly important aim for all three years, but only helps those undergraduates who are already self-motivated and have a clear idea of what their future goals are so as to take advantage of all the resources the degree provides to them.Both Year 1 and Year 2 undergraduates shared equally high scores on the expectations and experiences regarding the affective domain indicating a positive belief towards meaningful learning. In fact, undergraduates demonstrated characteristics of resilience and willingness to make mistakes as well as interest in extracurricular science related activities and a high percentage in goals of pursuing a job in science, all of which are indicators of intrinsic motivation. The fact that undergraduates’ interest in pursuing further graduate studies was low is possibly attributed to the fact that the university promoted and encouraged, through its curriculum, the development of key skills as part of their preparation for the workforce but also due to financial restrictions in pursuing further studies. Members of staff concerns on the affective value of practical work and possible triggers on anxiety signifies awareness and consideration of the domain, something demonstrated in their behaviours encouraging and promoting confidence in undergraduates, ensuring that the laboratory meets their needs. Furthermore belonging was satisfied through a positive laboratory culture promoting discussion and collaboration between peers. Even though undergraduates’ responses indicated intrinsic motivation, this does not negate that motivation is environment dependent. However, undergraduates with enough extrinsic motivation, something demonstrated on the role assessment played in their attendance, can have sufficient motivation to engage with activities that are not intrinsically motivating to them. Undergraduates who were invested in pursuing a career in sciences, even though they might disliked some practical work lessons, put the effort and maintained their interest due to being part of an environment which nurtured and cultivated their views in identifying with the Scientist Identity. Lastly, undergraduates’ need for autonomy and its effect on their motivation was deemed as unrealistic as undergraduates can not understand what they are observing without guidance and sufficient scaffolding from members of staff. However, openness of practical work lessons advance gradually and progressively as undergraduates develop their skills and their schemata regarding science related theoretical concepts. This was demonstrated in the fact that even though both Year 1 and Year 2 undergraduates both had their expectations met by experiencing the integration of the cognitive and affective domain in their practical work lessons, Year 2 undergraduates reported experiences exceeding previous expectations, something aligning with the way members of staff planned a spiral curriculum and the progressive nature of the aims of practical work throughout the 3 years of the degree offered. Again, even though affective and psychomotor domains can be activated, members of staff need to modify their practical work lesson structure so as to incorporate the cognitive domain in the right way by introducing undergraduates to scientific concepts and supporting them throughout their activities with pre-, during, and post- instructional interventions.

It is important to acknowledge that the mixed methods approach adopted in this research study sought to explore the effectiveness of practical work from different angles and it was not the intention to generalise universally but rather explain situations in case studies similar to the case study researched. Nevertheless, some findings concurred with those in other studies with regard to the challenges experienced and modifications a practical work lesson required in terms of teaching and structuring.

Whilst the significance of training undergraduates in developing their skills has been adequately addressed in the literature (Kerr, 1963; Khoon, 2004) the promotion of conceptual knowledge and effectiveness in doing so has been questioned due to the absence of such evidence (Boud, 1980; Hofstein & Luneta, 2004; Wang, 2005; Millar, 2009; Abrahams, 2011). This has led members of the science education community to question practical work's contribution to learning. Osborne (1998 p.156) argues that "practical work only has a strictly limited role to play in learning science and that much of it is of little educational value". In addition to that, Hodson (1991) claims that practical work "as practiced in many countries, it is ill-conceived, confusing and unproductive" (p.176). Perhaps a key phrase here is *as practiced*. It would be unreasonable to anticipate the development of conceptual knowledge as a direct result of practical work as an activity (Constantinou & Fotou, 2020). However, instead of merely questioning the effectiveness of practical work in expectation of a binary answer, a small number of recent studies (Galloway, 2015; Agustian & Seery, 2017; Seery, 2018), in agreement with this study's findings, shifted their focus in exploring strategies that can help clarifying *how* practical work can be effective. The deeper insight that this research study provides, and complementary to other published research, is how laboratory observations, undergraduates' responses to understanding science concepts and members of staff perceptions provided a multi-faceted and multi-layered view on how practical work is experienced, what it contributes towards concerning learning and how it can be improved.

This allowed the refinement of the conceptual frameworks used that, in combination with learning theories, current knowledge and consideration of factors impacting learning, led to a suggested model that indicates qualities in maximising the effectiveness of practical work as a teaching practice in life sciences. Additional insights that emphasised the undergraduates' perceptions towards their experiences with practical work lessons and members of staff' approaches in designing and structuring them, revealed how the laboratory lesson can be 'staged' in ways that can enhance the learning process as well as provide opportunities for meaningful learning through the integration of domains in the tripartite model discussed (Novak, 2010).

Reflections : Understanding practical work in Life Sciences

Millar (1987 p.113) aptly questioned " But what is this practical work for […]. " The findings of this present study demonstrate that the effectiveness of practical work is not binary, either happening or not. Undergraduates should be trained on how to do science, how to learn science and how to use science. Practical work is not a panacea neither a stand alone practice ; It is not the way *with which* learners will learn conceptual knowledge, but instead a means *through* which undergraduates can develop their theoretical understanding of science.

No man is an island, neither practical work is; the development of conceptual understanding in science is a result of reflective processing of performance during practical work lessons and information acquired from instructive practices such as teaching in or out of the laboratory. The laboratory can be regarded as a Vygotskian learning zone of proximal development where professionals guide undergraduates, through scaffolding, from being a novice and having limited knowledge to a point where skills and a better understanding on the scientific processes and theories is developed. Furthermore, practical work as an activity itself can be regarded as the starting point of a bigger learning zone of proximal development where undergraduates, through reflection from self-studying and information received in lectures, can potentially reach a more advanced level where they can process information by, for instance, writing a reflective laboratory report, and reaching a satisfactory and scientifically-backed understanding of the material taught (Constantinou, 2022).

Rather than asking if practical work is effective, we should explicitly distinguish and clarify, as it has already been done in previous research (Seery et al., 2018), *at which stage is*; *in what*; and *how* is practical work effective. As Kirschner et al. (2010) state " The epistemology of a discipline should not be confused with a pedagogy for teaching or learning it. The practice of a profession is not the same as learning to practice the profession" (p.83). Constructivism, being the most commonly attributed underlying philosophy of practical work, is a learning theory and not a pedagogical practice (Hobbiss, 2018). Taking into consideration the implementation of neuroscience in learning, neuroconstructivism advocates and similar to Kirschner et al. (2010), that in order to increase neuronal synaptic connections and promote multiple overlapping partial representations, learning in the laboratory should be guided, not unguided. This way, exposure to information in multiple ways and times, makes information more accessible and leads to learning. Perhaps purely constructivism methodologies can only have a positive effect to undergraduates who have adequately advanced their science knowledge to the level where they can scaffold themselves (Kirschner et al., 2006).

Most importantly, practical work should offer opportunities for meaningful learning and integration of the cognitive, affective and psychomotor domains; aims which should be clearly communicated and mutually aligned with expectations from both members of staff and undergraduates'. As specified in Ausubel's theory, a positive emotional state encourages the learners' engagement in entering the process of creating meaning, a responsibility falling upon both undergraduates and members of staff (Novak, 2010) . If we as educators, want to train and 'produce' graduates capable of thinking, creating, being innovative at a high level, we need to find a way to stop learners from being mere regurgitators. Learning requires space for self-thinking and reflecting, sharing, interacting and learning *with* peers and professionals (Fry et al.,2003). Additionally, undergraduates should be immersed in their discipline, in this case life sciences, as this immersion allows them to learn from and work in that culture (Latour & Woolgar, 1986). The way practical work lessons are structured should not be about transmitting knowledge but about helping undergraduates perceive and participate in the ideas and practices the science community uses to understand the world (Abbas et al, 2016).

Implications for practice

The laboratory is a financially costly learning environment to solely expect the teaching of theory and even considering otherwise, which theories should be incorporated in the curriculum for practical work instruction? (Seery,2020). The gordian knot between practical work and expectations on theoretical development as a direct result of it , should be cut. As Millar (1991) stated that it is neither desirable nor possible to completely separate theory form practical work. What findings of the present study indicate, and in agreement with Abrahams (2011), is that there is little evidence of "interplay" (p.127) between practical work activities and theory *in* the laboratory *while* conducting experiments. For this reason, bridging the domain of observables with the domain of ideas would be required if effective conceptual learning is to occur, but that does not need to happen *in the laboratory* and *as a result of practical work* but as a result of a bigger learning zone in which practical work is implemented, but contributes in its own way and for specific purposes; as demonstrated in the present study's findings.

Initially, there is a need for clearer communication between members of staff and undergraduates on what can realistically be expected to be achieved in terms of learning and doing in practical work lessons. Laboratory activities have been shouldered the expectations of contributing towards conceptual development of science despite the fact that their duration merely ranges 3-4 hours and their scope usually involves the training of undergraduates in developing their scientific skills, whilst processing laboratory protocols and handling equipment (Abrahams, 2011). Additionally, it is important for members of staff, as Millar (2004) and Abrahams (2011) point out, to acknowledge that conceptual knowledge does not directly emerge from observables. For this reason, constructivism theories should not be erroneously interpreted as pedagogical practices that can be applied in practical work lessons where undergraduates have not reached the level where their schemata are properly developed so as to efficiently construct knowledge on their own (Hobbiss, 2018). Instead, members of academic staff need to take into consideration and support their teaching practices with choices informed by neuroscience. As explained in neuroconstructivism (Mareschal et al., 2007) the brain constructs partial representations that capture the characteristics of the environment in which the information was originally stored (Hobbiss, 2018), therefore the information is easily accessed subsequently and stored in the long-term memory only after undergraduates will be exposed to several overlapping partial representation which can be enhanced through repetition. It is therefore not the discovery of a concept that is important for successful learning but the recurrent exposure to it and practice in accessing that information multiple times and in multiple ways (Hobbiss, 2018); this can be achieved through explicit instruction, peer collaboration, discussion and with what Vygotsky termed as scaffolding (Vygotsky,1978). This way, undergraduates are guided to make scientific observations through the eyes of professionals, in this case through negotiation of meanings (Bretz, 2013) with members of staff (Ogborn et al.,1996; Abrahams, 2011).

Taking into consideration time constraints under which practical work lessons are being delivered, by choosing expository type lessons (Abrahams, 2011) so as to balance to cognitive load imposed to undergraduates, an equal amount of time can be devoted in the development of skills but also in guiding them towards linking observables with ideas and building their metacognitive skills that will be required afterwards during self-studying, based on the model proposed in this present study (Chapter 5) and as supported by Taber (2011). Last but not least and most importantly, practical work lessons should identify experiences that that will provide undergraduates with the opportunity to experience meaningful learning through the integration of the cognitive, affective and psychomotor domain. By maintaining undergraduates' interest, meeting their needs, making lessons applicable to real-life scenarios and nurturing the science identity with which they were motivated to embark on their studies in science to begin with, can contribute in positive reinforcement towards learning meaningfully.

What should be taken into consideration and be acknowledged is the need for members of staff to clearly communicate and demonstrate that practical work, unlike the way it is commonly practiced in secondary school (Abrahams, 2011), is not just a conceptually undemanding hands-on activity but instead entails effortful training in thinking scientifically and bridging ideas with observations, at first through professional guidance.Practical work should be treated for what it is, and while the aim is to link observables with ideas, this study encourages us to be mindful on what can be practiced in the laboratory and what can be practiced outside of it, either online or in the lecture hall setting. Overall, as the teaching model suggested in Chapter 5 demonstrates, the effectiveness of learning with practical work depends on a carefully organised learning zone which extends outside the laboratory and co-currently outside the control of members of staff, as undergraduates too, as learners are required to be open to receive training and take the initiative for their learning.

As Kugel (1993) aptly phrases it

> *"Perhaps teaching is more like coaching. Perhaps the students' minds are less like pails to be filled than like muscles to be strengthened by exercise. Perhaps learning is something students do rather than something that is done to them".*

Limitations and suggestions for further research

The findings of this study have to be seen in light of some limitations which can be addressed in further research. Due to the inability to access grade records of undergraduates, there were no data on recruited students' abilities and thus it could be a group of undergraduates of specific ability who were able and prepared to answer questions correctly every time. It was; however, ensured that, in each laboratory, the observations and interviews started with a different group of undergraduates to that of the anterior observation session. With regard to the questioning method during practical work lessons, undergraduates were interviewed at different stages of the experiment, which, again, does not ensure that the questions asked were at all times of comparable difficulty. Regarding questionnaires distributed to assess opportunities for meaningful learning, all undergraduates in Year 1 and 2 had the opportunity to participate in providing their pre-laboratory expectations at the beginning of the academic year. However, due to timetabling challenges and access constraints to classes attended by all Year 1 undergraduates from different degrees in the life sciences department, only data from Year 2 undergraduates were collected as part of the questionnaires concerned with post-laboratory experiences at the end of the academic semester. Without Year 1 post-semester questionnaires, this study cannot provide firm conclusions regarding before and after comparisons of undergraduates' experiences concerning meaningful learning in the first year laboratory, although potential negative impact of Year 1 was expected to be seen in Year 2 questionnaires prior to the start of the academic year. However, findings were presented and conclusions were indicated with caution along with considerations for revaluation in further research. Additionally, due to the fact that questionnaires were collected in classes shared by all degrees offered in life sciences for Year 1 and Year 2, low scores indicating negative beliefs towards meaningful learning cannot be linked with specific practical work classes nor examined based on specific features that, as explained, could have a negative impact in learning (e.g. practical work classes without guidance, high cognitive load); this requires further investigation. Undergraduate comparisons between Year 1 and Year 2 are made using cross-sectional data. Ideally, a longitudinal study following the same cohort of undergraduates throughout Year 1, 2 and 3 would had been able to shed light on how practical work is experienced by the same people and yield more robust conclusions. However, limitations were balanced and strengths of the methodology used were enhanced by ensuring that internal and external factors such as university admission criteria, secondary school A level examination syllabus (post- AS and A level reformation in 2015), departmental modules' curriculum, design, practical work classes and members of staff teaching it, remained the same so that both Year 1 and Year 2 cohorts shared similar characteristics. Access to Year 3 undergraduates, which was constrained due to their focus on their final research project, would have allowed conclusions to be made on how undergraduates evolve in the three-year degree offered at the university with regard to skill and conceptual knowledge development in comparison to the more advanced type of inquiry practical work lessons attended. Lastly, it is considered necessary not only to assess undergraduate's understanding and recollections in the short-term and *in* the laboratory but also long-term; something which was not feasible as practical work classes could not revisited at future dates neither assessment reports could be accessed.

This paper presents a preliminary analysis of some of the collected data and although the reported results are representative of the institution recruited, there are no conclusions drawn as per the representativeness nor the generalisability of these findings in terms of all UK tertiary institutions offering life science degrees, at least not in quantitative sense. As outlined above, the methodological approach of the study was such that would enable a rich and contextualised understanding of some aspects of undergraduates' experiences of and in practical work through the intensive study of a single case study. To support this, questionnaires from undergraduates along with laboratory observations on lesson structure, undergraduates' conceptual understanding and members of staff perceptions were analysed, triangulated and compared against the curricular aims of the different life science degrees offered in the chosen institution where the research study was conducted. This approach supports a situational generalisability of the outcomes with broader inferences to be made on the basis of similarities between the case study reported here and other tertiary level institutions offering such degrees.

Whilst data can only demonstrate the effectiveness of practical work through the lens of different factors explained and discussed, the refinement of the theoretical framework by Millar et al. (1999) and Tiberghien (1996) suggests a guideline on a teaching model which has the potential to manifest positive results based on findings indicating the case in this present study and supported with published literature. This study calls for further research exploring the effectiveness of the aforementioned suggestions while also considers the need for renewed attention to the implementation of pre-laboratory activities. Additionally encouraging the incorporation of in-laboratory guidance and post-laboratory discussion within the framework of learning in the laboratory serves the purpose of training undergraduates to engage conceptually while doing practical work and getting prepared to enter an active learning zone with the necessary mental supplies to further reflect while self-studying. In this regard, it is anticipated that findings of this study as well as suggestions will assist university Life Science departments in making future lesson plan adjustments so as to serve the highest purpose of practical work that is the development of skills. Additionally, *through* practising practical work, undergraduates are being conditioned in developing conceptual understanding while immersing in its culture.

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