

Article

The Effectiveness of a Must-Have Practical Work in Tertiary Life Science Education

Marina Constantinou * and Nikolaos Fotou

School of Education, University of Lincoln, Lincoln LN6 7TS, UK; nFotou@lincoln.ac.uk

* Correspondence: mConstantinou@lincoln.ac.uk

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Abstract: The teaching of sciences has long been associated with practical work; an instructional tool that is believed to be effective in terms of both promoting learning as well as making the teaching of sciences enjoyable. However, empirical evidence on its effectiveness as a teaching method and whether it has any affective value for undergraduates is still lacking, when it has been deemed as one of the costliest aspects of science education. This paper reports on the preliminary 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 on conceptual understanding and motivating undergraduates according to the academic staff of a life sciences department. For the qualitative data presented here a questionnaire was administered to the academic staff who, along with Year 1 and Year 2 undergraduates, were interviewed and also observed during practical work classes. The preliminary findings showed that the perceived aims of practical work by the academic staff vary across years, while the observations revealed two types of lessons in which the importance of providing theoretical scaffolds during experiments so as to help undergraduates in linking concepts and theories with observables was prominent.

Keywords: practical work in tertiary education; undergraduate practical work; practical work in life sciences; practical work

1. Introduction

Practical work has been a didactical tool that had been for long, and indeed unquestionably, appreciated by teachers and academics for its inclusion in the biology and life sciences curriculum in secondary and tertiary education respectively. Whilst there has been a considerable amount of literature identifying the purposes of practical work and its effectiveness for secondary school education [1,2], its purpose and effectiveness in tertiary education remains unquestionable. Instead, past research on practical work in tertiary life sciences education, and science more generally, presents a subjective rhetoric [3] on the need for its inclusion in the curriculum than empirical knowledge on what the exact aims of practical work are and whether, and the degree to which, these are met.

Fifty-seven years after the publication of Kerr's ten suggested aims of practical work, [4], studies have shown that secondary school and university practical work [5,6] share the similar aims of conceptual understanding promotion, development of skills and motivation [1,2]; the main difference between the two being that secondary school education prioritises, at least for the first two years [4], the affective value of practical work over its effectiveness on conceptual understanding. The importance of such aims is indeed acknowledged by graduates and practising scientists who stressed the importance of practical skills development and the comparative insignificance of its affective value [7]. This focus on skills development could be attributed to the purposes of such undergraduate programmes in preparing students to enter the science industry rather than making them interested in the subject, something that is expected to be innate in that stage.

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

The effectiveness of a programme depends, among other factors, on a clearly structured curriculum which would potentially allow the maximisation of students' educational experience and would prepare job-ready graduates [8]. With practical work being an essential part of such programmes, empirical research on the perceived aims of those who deliver these programmes and practical work classes is essential.

2. Background: The Role and Aims of Practical Work

Practical work is often seen as of crucial importance to the appeal and effectiveness of science education at all different education levels. Within tertiary education, practical work constitutes an essential part of science and science related courses with a considerable amount of time and resources being spent in/on laboratories. Despite the differences in emphasis and absence of agreement upon the educational goals of practical work, many researchers in education and educators frequently share the same, or broadly similar, generic aims for the use of practical work in science related courses. A condensed list of such aims is based on the work of Buckley and Kempa [9], according to which practical work should aim at promoting the development of:

- (a) Manipulative skills;
- (b) Observational skills;
- (c) The ability to interpret experimental data;
- (d) The ability to plan experiments.

A more detailed list of practical work aims is derived from the early work of Kerr [5] in secondary education and the ten identified aims can be summarised as:

- (e) Teaching manipulative and observational skills;
- (f) Improving understanding of theoretical concepts, methods of scientific enquiry and develop expertise in using it;
- (g) Developing problem-solving skills;
- (h) Nurturing/developing professional attitudes.

Although the above aims have been about practical work in secondary education, they are common and can equally apply to science at tertiary level in general and life sciences in particular. As with every science and science related course, practical work allows life sciences to be taught in a manner and environment similar to that in a laboratory where research is generally conducted, and scientific knowledge is generated and tested. It is through the involvement of undergraduate students in such practical work where similar processes or equipment to those in research laboratories are used, ensuring, on the one hand, that universities meet the needs of industry and research laboratories for skilled scientists and highly trained researchers [10] and, on the other, that students better conceptualise the theoretical concepts and methods of scientific enquiry and develop expertise in using it.

2.1. *The Need for Practical Work in Tertiary Education: Evidence or Opinion Based?*

Achieving the above aims through practical work had constituted one of the main rationales for the inclusion of practical work in the curriculum of tertiary science and science related courses, life science courses included. Discerning voices, however, like that of Hawkes [11], have challenged this need for practical work arguing that "the enormous expenditure of time and treasure and student dislike of laboratory teaching demands substantial evidence that it has value commensurate with its cost and with the loss of subject matters that must be omitted to make time for it". This argument

has substance as only a minority of science and science-related students move into science-related jobs and laboratories once they graduate nowadays. For example, 74% of those who graduate in the USA with a major degree in science and science-related subjects find employment outside science and science-related areas [11], while similar is the case in the UK with a significant proportion of such graduates not being employed in science-related fields [12]. Nevertheless, it is rather impossible to know which students would follow a professional research-led or lab-based career, while rejecting the role of practical work on the basis that the professional and practical skills it helps in the development of, are only useful for a minority of science and science-related graduates which may leave the majority of students with the impression that such studies are mainly theoretical and abstract in nature and the related professional skills are non-transferable.

Similarly, the argument for the importance of practical work in enhancing undergraduates' learning and conceptual understanding has been questioned in a number of studies [9,13,14] decrying the absence of evidence on such an effectiveness. In Hofstein and Lunetta's [13] words, "(r)esearchers have not comprehensively examined the effects of laboratory instruction on student learning and growth in contrast to other modes of instruction, and there is insufficient data to confirm or reject convincingly many of the statements that have been made about the importance and effects of laboratory teaching".

This lack of evidence on either the effectiveness of practical work in developing practical (manipulative and observational skills) and professional skills, or facilitating undergraduates' learning is suggestive of the need for further research on the role of practical work in tertiary science and science related education. It is; therefore, important to think through the aims of laboratory work in terms of what graduates actually take away from practical work, the factors that make practical work successful, and in what terms, so that practical work may find appropriate in the tertiary science and science-related curriculum, thus further informing the way it is conducted at this level. Precisely, what needs to be further examined is the kind of objectives and aims that are attained in practical work and the range of factors these are dependent on. This paper suggests that, amongst others, these factors include the lecturer's perceptions of the importance of practical work, their aims for conducting practical work in their modules and courses and students' expectations of practical work.

2.2. The Study Focus

Over the last two decades, there has been a limited number of research studies [14–16] conducted to explore the effectiveness of practical work in attaining the many aims discussed above on a number of tertiary science courses. However, research is still lacking on life science courses, like biology, zoology, botany and environmental sciences, which are also, by their nature, both hands and minds-on inquiry-based disciplines and as such, practical work has been considered an essential part of their curriculums. However, as with every science and science related course, there has been very little justification given as per the inclusion of practical work in life sciences curriculums which has been assumed to be necessary and important than evidence based. This paper reports on the preliminary findings of a case study conducted at a British university to examine the perceived aims of practical work, the effectiveness of practical work in terms of promoting undergraduates' conceptual understanding and in motivating them in their studies according to academic staff of a life sciences department. These preliminary findings reported here address two of the main study research questions. These are:

- Is practical work effective in helping undergraduates build conceptual understanding in life sciences?
- What are the aims of practical work amongst a small sample of lecturers in the department of life sciences at the chosen university?

3. Study Design

This main study, part of which this paper draws on, used a mixed methods approach including student and lecturers' questionnaires, laboratory observations, and lecturers' interviews. As a thorough quantitative analysis and report on students' questionnaire responses that examined their perception

on the cognitive and affective value of practical work, is beyond the scope of this paper, the results present only data from the laboratory observations, interview with lecturers and their responses to Kerr's activity of ranking a predetermined list of practical work aims.

Background to the Case Study

This case study involved practical classes with undergraduates from different life science degrees. Specifically, undergraduates were recruited from all seven degrees offered at the School of Life Sciences including Ecology, Bioveterinary Sciences, Biomedical Sciences, Biology, Biochemistry, Animal Behaviour and Zoology. The institution where the research was conducted is a public research university in England, offering undergraduate and postgraduate degrees for the last 30 years. The school of Life Sciences has been running for approximately six years and all seven three-year degrees have an access policy which requires undergraduates to hold three A level (national) qualifications, including a Pass in the practical element, with a grade of BBB equivalent to 120–131 UCAS (The Universities and Colleges Admissions Service) tariff points. UCAS is a British organization operating application processing for higher education. Students' examination grades are converted into numerical values that correspond to UCAS Tariff points that universities refer to for their students' entry requirements [17]. Participants included first and second year undergraduates from the School of Life Sciences whose degree included degree-specific core laboratory classes along with classes shared with undergraduates across the school from all seven programs.

4. Materials and Methods

To situate the study that would provide an answer to the two questions above in a naturalistic and real-life educational context, semi-structured interviews were employed with Year 1 and 2 students and lecturers delivering practical work classes in the chosen tertiary institution. Additionally, a key focus of the research reported in this paper was students engaging in practical work in the laboratory and as a consequence, observations in the actual laboratory setting was another key tool. These also provided the opportunity to embed within the real learning context experienced by the participants and gain insights that would have been inaccessible by the use of other methods. This in situ nature of this overall methodological approach was also helpful in the data analysis and interpretation presented below.

An opportunistic sampling method was adopted, recruiting undergraduates from Year 1 ($n = 256$), undergraduates from Year 2 ($n = 211$), and lecturers ($n = 14$) from all seven programs being offered at the department with the latter being interviewed on their perceptions of the effectiveness of practical work whilst also completing a Kerr's activity [4] in which ten given aims of practical work were ranked in order of importance. Year 1 and 2 students were observed and interviewed in situ in the laboratory setting (a practical work class for the majority of core modules usually consisted of approximately 100 undergraduates), to assess them with respect to what they do and what they think of while doing practical work (six different practical work lessons were observed in total, three for each of Year 1 and 2).

The undergraduates were initially interviewed so as to examine whether they were both minds-on and hands-on with the experiments while working in the laboratory. The experiment protocol was thoroughly studied beforehand and, along with the help of the lecturers, probing questions about theory underlying the experiment were formulated and asked undergraduates to evaluate whether there was a minds-on approach (i.e., a theoretical understanding behind their actions to the experiment undertaken). This ranged from questions concerning the scientific theory underpinning the experiments or questions relevant to the different technical procedures required to conduct the experiment. Additionally, undergraduates were interviewed, while being observed, in order to examine the extent to which they could do what the lecturer expected them to do (e.g., pipetting, handling equipment and extracting DNA). Undergraduates were also informally assessed on whether they could recall information from their experiment in follow-up lessons. Some general questions that guided the semi structured

approach to the interview included the following questions (these were adapted in each laboratory session observed in accordance with the experiment conducted):

- Could you please explain to me, in your words, what are you doing with these devices and equipment? Why are you doing this? What is this showing you?
- How are the measurements taken and their analysis related to what you know?
- Could you please explain the reading that you got? Was it expected? Why?
- Could you please explain to me what equipment you will use for this part of the experiment and the reasons for this?
- Could you show me how you set up this equipment ready to use for the experiment to be conducted? Why this particular setting?

At the end of each laboratory, undergraduates were also questioned as per their feelings and thoughts about practical work and whether they were enjoying it.

Apart from the main interview questions, the Practical Activity Analysis inventory instrument developed by Millar [18] was used as a guideline to assess effectiveness at Level 1 (i.e., did students do what they were intended to do, and see what they were intended to see?) and effectiveness at Level 2 (i.e., did students learn what they were intended to learn?). The number of undergraduates giving correct answers was tallied and are provided in the following section.

In that part of the study this paper draws on, data triangulation methods were used to cross examine findings emerged from the different data sources [19]. For example, lecturers' responses to Kerr's activity and interviews were compared with laboratory observations, thus developing a more detailed understanding and a pragmatic view of practical work in the laboratory.

The theoretical framework presented in Figure 1 was used in the data analysis to examine the effectiveness of practical work in terms of the learning outcomes lecturers who designed and delivered the session initially set. The two domains distinguished here between those activities related with doing with observables and those with ideas can be further linked to the similar Tiberghien's and Abrahams' and Millar's [20,21] models. These models were used to assess the effectiveness of practical work that was the focus of this study by using the four levels in Figure 2 (i1,o1,i2,o2).

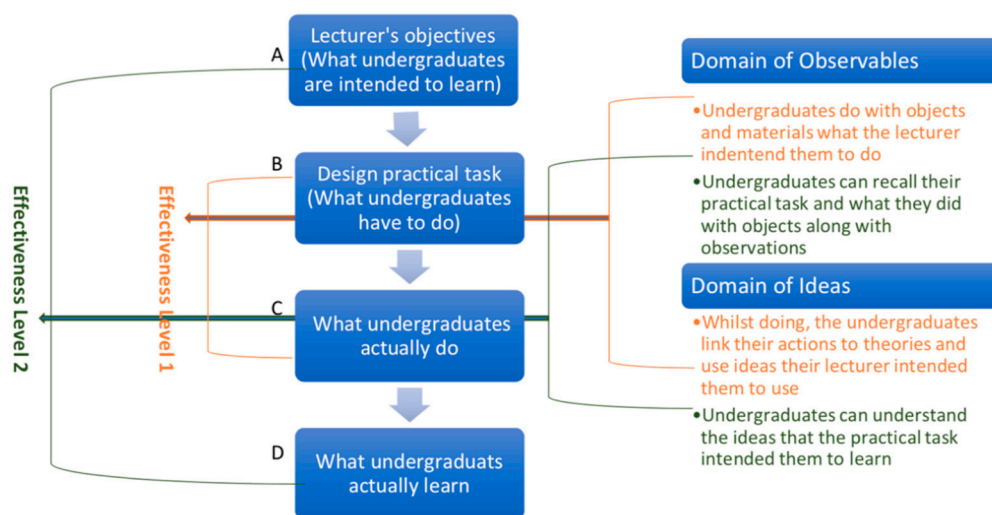


Figure 1. Theoretical model for the effectiveness of practical work. Adaptation from Millar et al. (1999) and Tiberghien [20,22].

Learning outcomes	Domain of observables (o)	Domain of ideas (i)
Level 1 (what undergraduates do)	1(o): “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]” [21]	1(i) “whilst carrying out the task, the [undergraduates] think about their actions and observations using the ideas that the [lecturer] intended them to use” [21]
Level 2 (what undergraduates learn)	2(o) “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” [21]	2(i) “the [undergraduates] can later show understanding of the ideas the task was designed to help them learn” [21]

Figure 2. Analytical framework for the effectiveness of practical work adapting domains of knowledge by Tiberghien [20] and levels of effectiveness by Abrahams and Millar (2008) [11]. Modified table by Abrahams and Millar [21].

5. Results

The results below are presented in summary form and in relation to the two research questions guiding this paper.

5.1. The Aims of Practical Work at the School of Life science

The aims of practical work, as previously discussed, are dependent upon the way the chosen School of Life Sciences runs the curriculum and structures practical work lessons. What differentiated practical lessons observed from each other were the aims of each lecturer designing the activities including, development of knowledge, development of skills, and developing understanding of the scientific approach to enquiry. From those practical lessons observed, four out of six included more than one objective, but overall a pattern was identified based on each year group. Table 1 presents the results of Kerr’s activity for the 14 lecturers recruited, with 1 being regarded as the most and 10 the least important aim. “Giving training in problem solving” was ranked as the most important aim for Year 2 and Year 3, whereas in Year 1 it was ranked amongst the least important aims. Instead, the most important aim for Year 1 was the promotion of “simple, common sense scientific methods of thought”. This same aim was ranked second for Year 2, whereas it was the least important aim for Year 3. “To be an integral part of the process of finding facts by investigation and arriving at principles” was ranked amongst the top aims for Year 3, but it was seen as amongst the least important aims for Year 1 and Year 2. Same was the case with the top aims for Year 3 (“To give training in problem solving” and “To be an integral part of the process of finding facts by investigation and arriving at principles”), which were the least important for Year 1. The same pattern is identified with Year 1, as its three most important aims, including “To promote simple common sense scientific methods of thought” and “To develop manipulative skills”, are assigned amongst the least important aims for Year 3. Year 2 includes a combination of Year 1 and Year 3 aims demonstrating an ‘in-between’ transitional period. Lastly, there is an agreement amongst all three years on the unimportance of doing practical work to fit the requirements of practical examination regulations, as it is ranked in the tenth position as the least important aim of practical work.

Table 1. Aims of practical work in undergraduate life sciences between years (Adopted by Kerr, 1963) [4].

	YEAR 1	YEAR 2	YEAR 3
1	To promote simple, common sense scientific methods of thought	To give training in problem solving	To give training in problem solving
2	To make physical phenomena more real through actual experience	To promote simple, common sense scientific methods of thought	To be an integral part of the process of finding facts by investigation and arriving at principles
3	To develop manipulative skills	To encourage accurate observation and careful recording	To encourage accurate observation and careful recording
4	To arouse and maintain interest in the subject	<ul style="list-style-type: none"> To make physical phenomena more real through actual experience To verify facts and principles already taught 	To make physical phenomena more real through actual experience
5	To encourage accurate observation and careful recording		<ul style="list-style-type: none"> To arouse and maintain interest in the subject To elucidate the theoretical work so as to aid comprehension
6	To verify facts and principles already taught	To arouse and maintain interest in the subject	
7	To elucidate the theoretical work so as to aid comprehension	To elucidate the theoretical work so as to aid comprehension	To develop manipulative skills
8	To give training in problem solving	To develop manipulative skills	To verify facts and principles already taught
9	To be an integral part of the process of finding facts by investigation and arriving at principles	To be an integral part of the process of finding facts by investigation and arriving at principles	To promote simple, common sense scientific methods of thought
10	To fit the requirements of practical examination regulations	To fit the requirements of practical examination regulations	To fit the requirements of practical examination regulations

5.2. Laboratory Observations and Discussions with Students

The in-situ observations of six different practical work lessons revealed two different types of classes that are presented in Table 2.

Table 2. Two types of instruction (A, B) during practical work lessons.

Type A Practical Work Lesson	Type B Practical Work Lesson
Undergraduates were not provided with instructions prior to the lesson and they were asked to read the information sheet and draw possible conclusions	Lecturers discussed main theories and underlying experiment ideas as well as main objectives and what undergraduates were expected to observe along with explanations on those observations prior to the experiment

Observations and interviews with the undergraduates showed that Type A practical work lessons focused more on the domain of objects and observables (hands-on learning) than the domain of ideas (minds-on learning) (Figure 1). Although some undergraduates could demonstrate an understanding of the underlying theories related to the practical activities they were working on, they were unable to relate those theories to their observations, even with significant prompting from academic staff or the interviewer. This was only accomplished when academic staff were providing explicit scaffolds relating the theory to what they were doing.

- Researcher: How was DNA amplified? Why do we have more DNA strands now?
- Student: No idea, I just read the protocol. Let me ask.
- Researcher: Let us think about this together. What does the polymerase chain reaction (PCR) do? Why do we heat the DNA?
- Student: We use PCR to make 'more' DNA. Heat 'destroys' it and then makes more' of it.

- Researcher: In a sense, yes. It denatures DNA, to separate it into two pieces of single strands so that it can get synthesized by an enzyme later.
- Student: Oh, I do not know. The machine does it anyway.

Type B sessions involved a discussion prior to the experiments where the lecturer introduced the main underlying theories and the ideas that should be used to explain observations and answer the question of interest. In this type of sessions, it was observed that undergraduates were actively engaged with the experiment, both minds-on and hands-on, since they could use ideas to conceptually understand what they were doing, thus bridging the domain of observables with that of ideas. The interview exchange below further attests to this:

- Researcher: Why do we have cold and hot phases in PCR? What is the machine doing now?
- Student: It has to support transcription. At first the DNA is broken down into two pieces while denaturing, I think. Isn't this the word Dr A used? Then when the temperature is cold it allows primers to stick and help in making a new DNA.

It should be noted that for both Year 1 and for Year 2, only one practical lesson out of the three observed had a conceptual development-related learning outcome, whereas the remaining two were designed with the aim that undergraduates will learn how to use a piece of laboratory equipment or allow undergraduates to follow a standard practical procedure. For Year 2 undergraduates, the understanding of the scientific approach to enquiry was also incorporated among the learning outcomes of the practical lesson. Overall, academic staff expected undergraduates to be able to report observations using scientific terminology and then, as they progressed to senior years, to be able to suggest a possible explanation for the data.

5.2.1. Effectiveness at Level 1

With regard to effectiveness at Level 1 (Table 3), in all of the practical work lessons observed, apart from one where equipment was introduced for the first time, the vast majority of undergraduates showed awareness and knowledge of how to use equipment after they were trained to do so, they were handling materials effectively and safely in relation to the given task, made precise measures, carried out routine procedures and could indeed follow oral and written instructions given. Mostly, it was only undergraduates of Type B practical lessons who were mainly able to explain the outcome and purpose of the activity, since it was being clarified at the beginning of the lesson. However, undergraduates found it difficult to talk about the activities in scientific terminology, as their explanations were, most of the time, oversimplified, with hints of ideas the lecturer introduced them to at the beginning of the lesson or pointed out while answering enquiries.

This is demonstrated in the interview excerpt below:

(Preparing slides with canine faecal samples)

- Researcher: Do you know what you are looking at down the microscope? (canine faecal sample)
- Student1: It looks disgusting but no.
- Researcher: What does the egg of the parasite look like?
- Student 2: Well, the egg is chubby but maybe what I am looking at is a bubble? No idea.

(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 structure 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.

Table 3. Effectiveness of practical work at Level 1. Summary of practical work lessons (six in total) that meet each criterion. Modified table by Millar [18] (p. 24).

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

5.2.2. Effectiveness at Level 2

Effectiveness at Level 2 (Figure 2) was assessed in terms of whether undergraduates could recall what they did with objects and observables and whether these could be linked to the practical work findings and underpinning theories the lecturer wanted them to learn. In all three practical lessons per year, a total of 107 undergraduates out of 256 for Year 1 (42%) and 85 undergraduates out of 211 (40%) for Year 2 were able to recall what they did with the main observables when asked in follow-up practical work lessons. With regard to undergraduates developing conceptual understanding of ideas that members of staff intended them to learn through practical work, a total number of 118 out of 256 Year 1 (46%) undergraduates and 93 out of 211 in Year 2 (44%), demonstrated an understanding of ideas particularly in Type B practical work lessons. An example of a conversation demonstrating understanding of main ideas is given below.

(Sex determination from cells)

- Researcher: What is amelogenin?
- Student (consensus in the 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.

5.3. Interviews with Academic Staff and Undergraduates

When academic staff were asked about the value and potential benefits of practical work, the 12 out of 14 thought that practical work was an important tool that allows undergraduates to develop a strong skillset that will allow them to further their career in science. They also believed that practical work supports undergraduates in understanding science better and that it has a strong affective value for those interested in following a science career. The responses of two of the lecturers below serve as examples:

- Lecturer 1: Practical work motivates students because we are giving them sufficient training in practical work that can be applied in the industry and clinical sector later. That is why they are studying sciences.
- Lecturer 2: Practical work motivates students who already have an idea of what they want to do in the future, so they take advantage of the practical sessions we offer.

In a similar manner, undergraduates, when asked about the affective value of practical work, believed that it helps them understand theory better by linking the domain of ideas with that of the domain of observables and materials. They also added that their experience in the laboratory allows them to recall information at any point in order to link their observations with the theory that they learn when studying. With regard to their affective value, their responses were mixed. Many undergraduates replied in a similar way to the one below:

- Student: We see things, and this helps reinforcing the theory. Theory makes sense when you see and do things on your own in the laboratory. It becomes more familiar. Even if we do not learn things in detail now or sometimes do not know what we are doing, we will go home, and we will recall what we saw in the lab and make sense of what we learned later (after studying the relevant material).

6. Discussion

These preliminary findings show that the effectiveness of practical work was related to the academic staff's intentions when designing the tasks. In agreement with other studies [23,24], there were laboratories observed in which undergraduates did not have a better understanding of underlying ideas and theories related to the practical work. Nonetheless, this does not, at least not necessarily, show ineffectiveness of practical work at that level as this was, to some extent, expected. Hence, conceptual development was not part of the academic staff's intentions when designing the tasks and it was ranked relatively low for all three years. On the contrary, in Type B lessons undergraduates had the opportunity and were indeed capable of linking concepts and theories to observables by not merely observing what they were intended to observe, as in Type A lessons, but they were also probed to think about their observations and link, in this way, the domain of observables with ideas and practical work underlying theories.

Moreover, interviews with undergraduates showed that they were confident in stating that practical work was the reason that they could remember what they learned in the laboratory and they could therefore use those experiences while studying at home, linking again, on their own, the two domains (observables with ideas). From what they argued, these experiences enabled them to understand theory better, something that aligns with one of the highest ranked aims for Year 1 classes ('To make physical phenomena more real through actual experience'). Despite their claims, the findings showed that less than half of them could recall practical work findings and related theories in follow-up sessions with most remembering scattered information. Similar findings were reported with secondary school students who were mainly able to recollect details or aspects of their practical work lesson which were novel, unusual or had a "visual, aural or olfactory component" [21].

Overall, practical work was effective in terms of developing of manipulative skills and promoting simple scientific methods of thought which both were deemed by academic staff as important.

Hence, undergraduates were doing what they were intended to do and seeing 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 the academic 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 laboratory and/or science-related job.

With regard to the affective value, and although this was not directly assessed, lecturers 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.

7. Conclusions, Limitations and Future 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.

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. 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. The authors are further addressing the main study research questions and this situational generalisability in the next iteration of the study, where questionnaires from students are analysed and triangulated with the data reported here and compared against the curricular aims of the different life science degrees offered in the chosen institution.

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