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Developing a virtual laboratory module for forensic science degree programmes

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A B S T R A C T

Laboratory work is essential in forensic science degree courses. They provide students with an opportunity to put theory into practice, as well as develop relevant professional laboratory skills through a case-based learning framework. Traditional laboratory instruction involves the use of a written laboratory script or manual that details the laboratory procedures and techniques for an experiment. Occasionally, instructors may provide a brief in-person demonstration of a critical aspect of the experimental procedure during the session. Since the coronavirus pandemic, the use of virtual laboratory (vLab) resources, such as video demonstrations, in teaching science practical skills has increased. These resources may be used alone or in combination with in-person laboratory sessions in a flipped learning model. Previous research has shown that vLab resources could enhance students' knowledge, confidence, and experience inside the laboratory. This study aimed to explore the perceptions and attitudes of forensic science students toward the use of a vLab module. Three videos were created in which procedures for carrying out presumptive tests, screening exhibits, and recording examinations were demonstrated. Seven undergraduate students enrolled at different stages of a forensic science degree programme were introduced to the vLab module and interviewed using a semi-structured interview approach. Through a thematic synthesis of the interview transcripts, we found that the implementation of an inclusive vLab module could enhance students' knowledge, confidence, and independence in carrying out forensic science laboratory procedures.

1. Introduction

Forensic science has a "distinctive" signature pedagogy encompassing the three fundamental areas of professional work [1,2]. The first aspect of how "to think" involves the probabilistic interpretation, evaluation, and presentation of scientific evidence [3]. The second aspect of how "to perform" defines specific standards for the identification, recovery, examination, and analysis of evidential items [4]. The last aspect of "acting with integrity" requires scientists to be objective, impartial, and transparent through processes such as maintenance of the chain of custody of evidence and contemporaneous notes taking. To achieve the above pedagogical outcomes, forensic science education incorporates problem-based, case-based, and project-based learning (PCPL) involving extensive crime scene, laboratory work, and courtroom presentations [5].

During the COVID-19 lockdown period (2020–2021), traditional laboratory sessions were severely disrupted. Students enrolled in science courses, such as forensic science degree programmes, were unable to complete most of their on-campus laboratory learning, which is essential for professional skill development and required by accreditation standards [6,7]. These challenges led to the development and use of virtual laboratory/ practical resources [8,9] to ensure the continuity of learning and to prepare students for in-person laboratory learning. This project was conceptualised during the lockdown period and aimed to explore the potential value of the use of virtual laboratory (vLab) resources to support in-person laboratory learning of forensic science techniques in the post-COVID-19 world.

1.1. Styles of laboratory instruction

Face-to-face laboratory learning is extremely important because it enables scientific concepts and theories to be better understood, while at the same time, enabling students to get practical experience with the science they are studying [10]. Inside the laboratory, students are given

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the opportunity to learn actively [11]. Conventional laboratory instructions are the traditional style of instruction where there is face-to-face attendance. Students are provided with instruction manuals where, most of the time, they are asked to follow a procedure that has a known outcome [12]. This traditional style is described as a cookbook, deductive, or expository [13].

There are four styles of laboratory instruction: expository, problem-based, inquiry, and discovery (EPID) [13]. The expository or conventional style of laboratory instruction is the most common in first-year university practical classes. Experiments are designed at a standard level with very little need to analyse any data, and the results are already known. The problem-based, inquiry, and discovery styles of instruction are less traditional and follow a more complex approach. These styles are commonly used in levels 5 to 7 (second to final year/postgraduate) and students at these levels require less supervision. The approach forces students to become more independent as they are required to choose the best process for carrying out experiments [12,13].

While almost all university laboratory sessions are taught in person, virtual or remote laboratory methods could be implemented to support science degree programmes. As stated earlier, these virtual approaches are becoming more acceptable due to advances in technology, coupled with global public health issues, such as the coronavirus pandemic [14,15]. With the use of vLab demonstrations, students will be able to watch an expert carry out a procedure they are also required to perform. Virtual laboratory game simulations, such as Labster, also allow students to carry out experiments virtually and may be configured to incorporate the classic styles of laboratory instructions (- EPID).

1.2. Learning styles and uncertainty in the laboratory

A major disadvantage of the virtual model of laboratory instruction is that it challenges the established theory of *"learning by doing"*, that is, physically carrying out a procedure in the laboratory [11,16–18]. It is thought that students may not be interested in their field of study if vLab exercises were to substitute in-person ones [11,17]. Although this resource cannot substitute face-to-face practical classes, it can help students prepare, consolidate their practical understanding, and evaluate their performance in the laboratory [11,16,19]. Moreover, students typically carry out a procedure inside the laboratory once or just a few times. If vLab demonstrations or simulations are available, they can support students' revision of key concepts and skills. Learners can recall more when information is presented to them multiple times [20]. Based on learning through repetition [20], learners would be able to recall the information, or in this study's context, the laboratory procedure better and would possibly enhance their learning process.

One of the principles of learning is the role of factual knowledge and conceptual frameworks in understanding. In order for students to become competent in any concept or technique, their factual knowledge needs to be deeply established. Furthermore, there also needs to be an understanding of facts and ideas in a conceptual framework along with a good knowledge organisation that enables students to retrieve and apply it [21]. Although students can learn a technique by physically doing it, even if they do not have access to any previous knowledge regarding the procedure, learning with understanding can significantly enhance their performance [21]. In science education, lectures and laboratory scripts are provided prior to an in-person practical session to enable students to understand the procedure they are required to carry out in the laboratory. Teaching experiences are usually standardized for all students but in any learning environment there are different types of students with different ways of learning. This happens due to many factors, such as differences in cultural, educational, and family backgrounds [21]. Against this backdrop, standardized laboratory-based teaching and learning may lack inclusivity. The use of laboratory scripts does not always accommodate all the different learning styles or learners' needs.

Although evidence on the impact of learning styles is lacking [22–24], cognitive science has established that learners exhibit differences that may influence outcomes and performance [25–29]. Visual, auditory and kinaesthetic (VAK) are three general learning styles described in the literature [23]. It is thought that visual learners learn better with the use of pictures or graphs. Their understanding process depends more on the body language of the teacher or instructor. On the other hand, listening to lectures or reading is more helpful to auditory learners. They use pitch, speed, and emphasis as means to understand and interpret information. Lastly, kinaesthetic learners are thought to learn better by doing, meaning getting 'hands-on' experience is more efficient for them. Physical world interaction is very important for kinaesthetic learners and they tend to lose focus quite easily [30]. Whilst learners report differences in their preferred learning mode, the available evidence suggests that learning material should be delivered based on the nature of the content and the background of learners [28].

The nature of forensic science practicals requires the integration of visual, auditory, and kinaesthetic aspects to provide adequate learning opportunities to all learners. Although the relationship between preferred learning modes and performance is contentious, it is acknowledged in the existing evidence that effective learning will not always be achieved when the learner is not acquiring the information in a way that suits their understanding process [30,31]. If a person prefers a visual mode of learning and the information they receive is not in a visual way, they may not show a good understanding, and in a laboratory scenario, they might be unsure of what to do when carrying out an experiment or a technique. In carrying out a laboratory procedure, there is a goal to be achieved. The procedure will include a starting point and an endpoint with specific intervening steps that need to be taken to complete the task. Having an experimental plan/ strategy is important to successfully complete the laboratory procedure. If learners are unsure and uncertain about the experimental strategy, their levels of "psychological entropy" may increase, which can result in anxiety [32].

Psychological entropy describes the association between uncertainty and anxiety levels experienced by a person [32]. Uncertainty consists of two primary domains. One is the uncertainty of action and the other one is the uncertainty of perception. A given situation can bring conflicts of action and perception, which can explain uncertainty psychologically. When a given environment is familiar, the brain will habitually respond and estimate likely outcomes of the situation that are reliable, which will then enable the brain to settle quite quickly in a specific behavioural-perceptual frame. Due to this, a person may be able to operate more efficiently. If a situation contains many perceived possibilities, the uncertainty experienced may be greater. Since individuals do not like uncertainty, they adopt strategies to decrease it, which can cause psychological discomfort. Furthermore, the goals being pursued by an individual can bias their actions and perceptions in line with information about the goal. Therefore, when there is a goal, possible perceptions, and actions are distributed to specific behaviours and interpretive frames that will result in the creation of the most optimal path to the goal. Things that happen around the world can make an individual more uncertain if obstacles are added when pursuing a goal or make them less uncertain if there is a clear path to that goal. If the pursuit of a goal is challenged, experiences of anxiety are likely to occur. This happens because the experience of anxiety is associated with uncertainty, and brain circuits that are related to anxiety are activated [32].

Uncertainty is not something that students should experience when entering the laboratory. Other than anxiety, it is possible that it can also cause low confidence in individuals [33]. Uncertainty can be minimised if an individual is familiar with an environment and is aware of responses they need to make to achieve a goal [32]. As mentioned earlier, if students learn with a learning style different from the one that suits them best for the understanding of a topic, they might be uncertain inside the laboratory. Considering the differences in the background of learners, their preferred learning modes, and the discussion about uncertainty, the use of a vLab module that utilises visual demonstrations of techniques, providing audio explanation with subtitles, used in conjunction with in-person practical sessions, could possibly help all types of learners learn better and possibly be less uncertain, more confident, and independent inside the laboratory.

1.3. Research on the use of virtual laboratory resources

The use of vLab demonstrations has been researched in many fields of science. Croker *et al.* [16] found that the educational experience of students was improved when their practical modules were supported with virtual video demonstrations. Students' attendance increased as the videos were available to them prior to the practical session, and even though the videos were not of high quality, they were considered as 'good enough' by students [16]. The study also observed that students' autonomy during the laboratory increased, and students seemed to learn more efficiently by having meaningful interactions with their teachers. The videos were also available to students after the laboratory practical, which enabled them to use the videos for revision purposes [16]. The authors concluded that the vLab resources could be easily adopted by most teaching laboratories, as the production of the videos was easy and of low cost.

Another study [11] on a biology module compared the perspectives and opinions of students about using only virtual laboratory demonstrations, only face-to-face labs, and using both virtual and physical labs. The study showed that when students used only video demonstrations to prepare for carrying out a physical lab session, their confidence, knowledge, and experience in the laboratory were enhanced [11]. Having the video demonstrations available to them prior to and after the practical, enabled them to take notes and enhanced their learning and practical experience. As a result, when performing in the laboratory, their courage and motivation were increased, as they did not think about making mistakes. The use of the virtual tool showed that on its own it can have a positive effect on the completion of a laboratory procedure, even though the study was not conducted to substitute in-person labs [11]. Moreover, Biochemical-Engineering research [34] on using videos to enhance laboratory experience has also found that there are affective and cognitive benefits for science students when virtual laboratory resources are made available. Students were able to go back to the videos to revise the laboratory procedure and watch it as fast or as slow as they wanted [34].

The use of virtual laboratory demonstrations has also been promoted by teaching laboratory technicians. Among this group, it is thought that students are able to perform better when exposed to vLab resources as they are more accurate and reliable during practical procedures. This made students discuss the techniques' effects rather than focusing on the implementation of the practical itself [19]. Generally, the available evidence suggests that students engage more in conversations about the practical sessions and results of experiments, rather than just carrying out the practical itself when vLab demonstrations are provided [16,34–36].

The University of Bristol, in 2005, introduced a vLab manual named Dynamic Laboratory Manual (DLM) which included online tests and video demonstrations to watch before a laboratory session. Students found these materials very exciting and helped them manage their time in the laboratory since the material was promoted and provided before the face-to-face practical session. It was found that the use of the vLab manual enhanced students' learning and interaction during the laboratory session [37,38]. In addition, the DLM acted as a 'rehearsal' before the laboratory and included glossaries of equipment and reagents, which was very helpful for students whose first language was not English. They were able to practice English by undertaking activities through the DLM. The DLM also gave them the opportunity of creating a mental framework of laboratory practical sessions, which enabled students to focus more on the specifics of a technique. Familiarising themselves with the language, students showed more optimism in their practical sessions [37,38].

1.4. Research aims

As much as a vLab module could help enhance students' knowledge, it is an evolving learning method, and its foundation should be informed by qualitative analysis [39] of students' perspectives. Students' experiences and ideas provide rich information that enables pedagogists to understand their different learning needs [21]. This understanding will allow practitioners to identify best practices and effective approaches for the design and delivery of vLab resources to enhance and sustain students' engagement and performance in forensic science programmes [40,41]. Available studies on vLab resources have mainly focused on the fields of Biology, Physics, Chemistry, and Engineering. There is limited literature on students' perspectives of vLab resources in the field of forensic science. The aim of this project was to investigate forensic science students' perspectives on laboratory work and the implementation of a virtual interactive laboratory module on forensic biology practical procedures and techniques. The project involved the video recording of a set of basic forensic biology laboratory examinations, the creation of a short online interactive module, and qualitative interviews with forensic science students.

2. Methods

This study utilised a qualitative method to understand students' perspectives on the use of vLab demonstrations within the forensic science field. Qualitative research methods are typically used when the research goal is to obtain "depth of understanding" of a phenomenon/concept [42,43]. In contrast, quantitative social research methods (such as surveys) are used to obtain the "breadth of understanding" of a phenomenon, with an aim of statistical generalisation of results [44]. The rationale for this study was to obtain in-depth theoretical perspectives about the value of vLab resources to forensic science students, which can inform the design of such resources to support the delivery of forensic courses. The study was conducted between September 2021 and April 2022 following ethical approval by the Departmental Ethics Committee (Ref No.: 39827). The qualitative method used was semi-structured interviewing, as it is a very versatile research method, providing the researcher with some degree of structure and flexibility in acquiring relevant data, changing/adapting questions, or producing new ones, based on participants' responses [44]. Moreover, this method enables participants to go more in-depth about their opinion and thoughts on the specific topic of interest.

2.1. Sample

Participants for the study were recruited using the purposive sampling strategy [44]. The reason behind this type of sampling was the need to acquire participants based on the information they could provide. In this case, forensic science students at different levels of their degree programmes had the right learning experiences to answer this study's question. Direct informal requests were sent to participants with the only criteria for participation being enrolment in a forensic science degree programme. On the day of each interview, an approved information sheet was provided to the participant along with a consent form. The interviewees were briefed on the purpose of the study, what they would be doing for the study, and how their responses will be kept confidential and secured. They were also provided with the researcher's contact details in case they wanted to withdraw or ask anything about the research. After the interviewees returned the signed consent form to the researcher, and the preamble was read out loud along with informing them that the recording was about to begin, the interview commenced.

2.1.1. Participant characteristics

The participants for this study were seven undergraduate students studying a forensic science degree programme. Although there were about 400 students enrolled in a forensic degree programme at our institution, about 7 – 15 interviewees were considered to be adequate for this initial project based on recommendations on sample size for qualitative studies and to prevent saturation [44]. Further, the qualitative analysis was not aimed at a statistical generalisation of results [44 *p399*,45] but to obtain in-depth theoretical views on students' perspectives about the use of vLabs in forensic science. Of the seven students who enrolled in the project, two were second-year students and five were third-year students (Fig. 1). Ethnographic characteristics of participants were not taken into consideration as this study focuses only on participants' perspectives on the use of the interactive video demonstrations. In the course of the interview, however, a majority of participants mentioned that English was not their first language, and this characteristic was found to be relevant in the synthesis of the results.

2.2. Video demonstrations

The techniques that were demonstrated in the videos were selected from first and second-year laboratory practical sessions on body fluids: 1) indirect presumptive test for blood using the leucomalachite green (LMG) reagent, 2) process for examination of an exhibit for blood, 3) direct presumptive test for blood using the LMG reagent [46]. All participants of the study had already completed an in-person laboratory practical on body fluids involving the above techniques. The three specific procedures were chosen because of how simple but simultaneously important they are for students. A laboratory script about the three demonstrations was developed, based on the existing manuals from a second-year module on body fluids.

To capture the three procedures, the CANON EOS M50 camera (CANON Inc., Taiwan) was used to produce high-quality footage. A tripod was used to assist in filming the demonstrations, and to minimise camera shake. Each demonstration was carried out twice or three times, each time from a different angle, so after the editing, the viewer is able to get different perspectives. The video recordings were transferred onto a computer and exported into an editing software. The editing was carried out using Adobe Premiere Pro v 14.3 (Adobe Inc., California). The video editing software was used to combine the video clips, cut off the audio to ensure no background noise was present, and apply texts and other necessary effects. Lastly, three scripts were written for narration purposes. The audio was recorded and added to the final cut of the videos, on Adobe Premier Pro. Moreover, subtitles were added manually to the editing software. The videos were then uploaded on Panopto (Panopto Inc., Seattle), and quizzes associated with the practical techniques were added throughout each video and labelled as 'knowledge check'.

2.3. Interview questions

An interview guide was created [44], consisting of three main questions, to facilitate the interview, ensure comparability among interviewees and enable participants to express their opinions and perspectives about the vLab demonstrations. The questions explored students' experience working in the laboratory, their views on the use of vLab modules, and their views on the video demonstrations on blood examinations. Probing questions were used as well, depending on how much participants' answers were relevant and/or answered the research question. An example from the questions included was, 'Do you think the video demonstrations could improve your independence in the laboratory?' (See supplementary material A).

Before the interview started, the interviewer summarised the information sheet and talked to the participant about the safeguarding issues. The face-to-face interviews were carried out in the university podcast room, where recording devices were available. The video demonstrations were shown to participants in-between questions. The participants were first asked about previous experience carrying out laboratory practicals. Then, after receiving a summary of what a vLab demonstration is, they were asked about their views on using video demonstrations. The video demonstrations created were shown halfway into the interview so that when participants answered the first questions, they would not be biased. After participants finished watching the interactive videos, they answered the rest of the questions mentioned previously. The recordings were stored on a password-protected computer which could be accessed only by the researchers. At the end of the interview, participants were asked whether they had anything to add or not and if they had any suggestions for the video demonstrations. The interviews lasted for about 20 to 30 minutes. After the interview was completed and had stopped being recorded, the participants were thanked for their participation.

2.3.1. Transcription of data

The interview recordings were uploaded on otter.ai (Otter.ai, California) which is a transcribing software. A text was produced where editing was possible. The transcription texts were then edited and proofread whilst listening to the audio recordings in case any mistakes were made by the transcription software. No names or organisations were mentioned in the interviews, therefore there was no requirement to blank out any data. During the editing of the texts, certain words/themes that seemed important were highlighted to help the analysis of the data. One hour was dedicated to each interview's transcription. The audio recordings were all deleted once all transcriptions were carried out.

2.4. Data analysis procedure

Data derived from the interviews were manually analysed using thematic analysis, which is a method where patterns of key themes are identified, analysed, and reported [47]. Thematic analysis was the chosen method for this study as it enabled the researchers to acquire data rich in information as well as point out key themes that all participants' answers had. Not only did it allow the researchers to get an understanding of participants' laboratory experience, but also their thoughts and opinions on the use of a vLab module in forensic science.

Firstly, the data had to become familiar to the researchers, which was

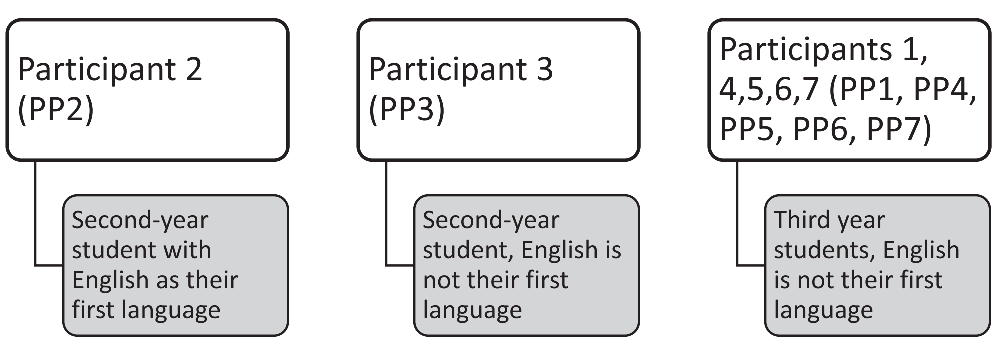

Fig. 1. Characteristics of study participants.

achieved by highlighting important aspects directly linked to the research aims whilst reading the interview transcripts multiple times. Subsequently, codes were assigned to the highlighted text in order to identify any pattern. Throughout the whole process, the data was revisited multiple times as it is important that the whole data set is represented in the codes, which were then categorised into themes. Key themes were then identified.

3. Results and discussion

In this study, students' experiences with laboratory practical sessions, as well as their opinions and thoughts on the use of a vLab module, were explored. The main theme identified from the qualitative interviews was the enhancement of students' *confidence*, *independence,* and *knowledge* in carrying out laboratory techniques using the vLab module as a learning resource. Two subthemes identified were the potential for the vLab module to decrease students' levels of uncertainty during face-to-face lab sessions and promote inclusive learning. When asked about their previous experience in the laboratory, there was a mutual agreement among participants that, despite being prepared or not, sometimes there was uncertainty about what to do in the laboratory, and a vLab module could decrease that uncertainty [32]. Further, the participants thought there was a lack of inclusivity regarding laboratory preparation, with most students stating they are visual learners (n = 4), and that they would like to observe someone else carry out a procedure they are required to do as well. Fig. 2 summarises the interaction between these key findings.

3.1. Virtual lab module enhances confidence, independence, and knowledge

The data revealed that the use of a vLab module can enhance students' confidence, independence, and knowledge. Before and after watching the video demonstrations, all participants (n = 7) reported that the video demonstrations would be or are useful for learning practical techniques. Almost all student participants (n = 6) claimed that after watching the vLab demonstrations, their knowledge of the procedures and techniques showcased had been improved and/or refreshed. The data showed that students were satisfied with the information about the specific techniques included in the videos. Participants thought the vLab module encapsulates all the necessary information needed to understand the laboratory procedure:

> "I think it's very cool. I think it showcase everything that we need to know. That's pretty straightforward. I feel like everyone could understand it." – PP1.
>
> *"I done these things. But it was long time ago. I have a really bad memory. So yeah, but yeah, I think it was, it was really like simple side. So it gave me actually more informations, than if I read some, like, academic sources on this, it was like, it was straight to the point. So it gave me more than actually reading something long. So yeah." – PP2.*
>
> *"Yeah, I feel like now I know that you have to do it on the side of the filter paper you actually touch the blood with rather than.. Yeah, definitely. I think if I had to do, like, I'd remember that. I go off of what you did." – PP3.*

The above findings are consistent with previous studies that have demonstrated that virtual laboratory resources can improve students' knowledge and understanding of practical techniques [11]. Further, students are more likely to engage in a critical discussion of the techniques when exposed to the virtual laboratory resources, promoting a more in-depth understanding of the technique, rather than just carrying it out [16,19,34–36].

Previous studies suggest that attendance increases when vLab resources are made available to students before their face-to-face session [16]. This observation is linked to improved confidence and interest in the laboratory practical, facilitated by the vLab resources. In our study, students' perceptions of the vLab module supported this finding, since the videos were described as *"fun and interesting"*:

> "… it gives me all the information I need to know. And, you know, it makes me excited… For what I'm going to do." – PP1.

Data from this study also showed that participants' confidence and independence can be enhanced by using the vLab module as a learning tool in forensic science. This was in line with findings by Maldarelli *et al.* that demonstrated that vLab resources enable students to perform techniques with more confidence and courage as there is limited questioning of errors [11]. Almost all participants (n = 6) in our study claimed that, after watching the video demonstrations in the vLab module, they will be more confident and independent when carrying out forensic blood examinations:

> *"Oh, definitely. I was always hoping that I'm going to be in the pair with someone who understands. … this would help to not be so stressed about who I'm going to be paired up with, to know actually what to do. If I would need to go to the lab … I would definitely be more confident in what to do. Because yeah, brain forgets. I did forget some of the steps. So I think this would be really helpful." – PP7*

It was found that the level of study of participants was linked to their views on whether the vLab module could enhance their knowledge, confidence, and independence in carrying out the technique. A few of the third-year students (n = 2) stated that their confidence was not enhanced in the specific procedures demonstrated in the vLab module:

> *"If I was on level four, I would probably say yes, more confidently, but now, I think I already know it. So it didn't add… If it was a completely different thing, something I've never done before. Probably. Yeah." – PP4.*

Some of the video demonstrations were derived from level 4 laboratory practical sessions, in which an expository style of instruction is typically used. It would make sense then that a video demonstration of first-year laboratory practicals would not be as useful to an already more independent third-year student, to whom practical sessions require less supervision [13]. However, overall, all participants (n = 7) agreed that the vLab module was an invaluable resource for revision as they are available to students even after the laboratory practical [34].

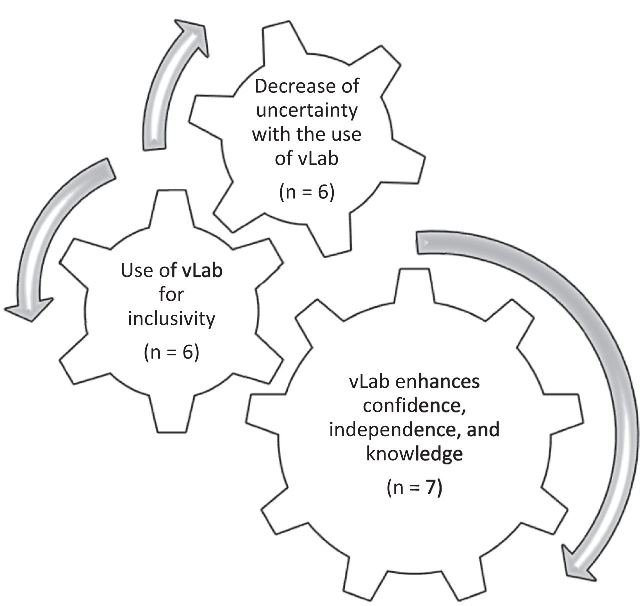

Fig. 2. Thematic map displaying students' experiences and opinions on the use of a virtual laboratory (vLab) module in teaching forensic science practical techniques.

3.2. Use of virtual laboratory modules for inclusivity

The first sub-theme from the interviews suggested that traditional laboratory instructions are not inclusive. Students whose first language is not English (n = 6: PP1, PP3, PP4, PP5, PP6, and PP7) reported that they were not fully able to understand laboratory scripts due to their professional and scientific manner, which resulted in sometimes not knowing how to carry out a technique. They were also not able to fully engage during laboratory sessions due to the language barrier. We found that the use of a vLab module could help bridge this gap and support students in their preparation for face-to-face laboratory sessions and provide them with a better understanding of forensic techniques. Similar findings were seen in a study from the University of Bristol where non-native English speakers reported positive laboratory experience following the introduction of a vLab manual embedded with glossaries [37,38]. Engaging with the vLab manual, students were able to practice English and have a better framework of the face-to-face laboratory sessions, which enabled them to focus more on the specifics of a procedure [37,38]:

> *"…For me, for example, in first year, I think that would be much more helpful, because I didn't understand, with my English, 100 % of what's happening. Yeah. So, I think, If I would see it, like demonstrated that would really help me to know what I'm supposed to expect in the lab." - PP7*
>
> *"Yeah, on how to do it and you don't, cause sometimes things are not written down.. easy enough for everyone to understand. So like the instructions you need to follow. Sometimes they are more. I don't know, scientific and more professional. … So seeing the video before, it will just save you time of trying to figure out. Why am I reading here? What do I need to do? Yeah." – PP4*

All the study participants (n = 7) emphasized the importance of having an expert demonstrate a procedure they are required to carry out in the laboratory. According to participants, they will prepare much better if they have a visual representation of the laboratory script and of what they are supposed to do. This would make sense since most participants (n = 4) claimed that they preferred visual learning. Students that reported they learn better visually, also reported that the video demonstrations were "*fun and interesting*". These findings are partly supported by cognitive science research on the different types of learners and how they receive and understand information, which may result in a better learning experience, although impact on performance and outcomes is controversial [23–25,27]. If the participants of this study prefer visual learning, they may report a positive learning experience by observing their teacher or instructor and their body language, either in person or in a video demonstration [22,23,30]. Using a vLab module as a learning tool was also thought to enhance inclusivity by having voice-overs and subtitles, which integrates aspects of auditory learning styles, such as listening and reading [23,30]:

> "…I'm a person that I understand more easily, visually. When I saw something, and someone shows me. It's much more easier for me." – PP5.

Although participants shared positive views about the value of the vLab module, they emphasised that the vLab module should not substitute face-to-face laboratory sessions. It was established from the interviews that the optimal way to learn and understand a laboratory technique was by attending in-person laboratory sessions in conjunction with the use of laboratory scripts and vLab demonstrations. This finding is supported by the principle of 'learning by doing', where students learn more efficiently by carrying out a procedure themselves [48]. Furthermore, the findings of a study that compared students' opinions about using only video demonstrations, only in-person laboratory sessions, and a combination of both showed that students performed better with the combination of both approaches [11].

> "Oh, like not a full alternative, like partial, maybe but not full, it doesn't give you the experience." – PP2
>
> *"I wouldn't want to, I can see their purpose in different circumstances. … But … you need the experience, you need actually to go in and do it and practice yourself. So yeah, I wouldn't recommend to substitute, if it's not necessary." – PP4*
>
> *"I mean, I think so like I would prefer to be in a lab to feel like I'm getting hands on. But I know that when we did a module last year with the virtual lab, like I still understood it, and I was like, I use what I learned last year, online now in that actual lab, so I feel like I wouldn't say that replace them, but they could be you know, in times like COVID and stuff like it. You know, it did work. It wasn't like it was useless because it did work. And it did help." – PP3*

The above views suggest that vLab modules in forensic science should not be designed as a substitute for in-person laboratory sessions but as a complementary resource. A combination of both a vLab module and in-person sessions is thought to be more inclusive as it would accommodate all the preferred learning styles.

3.3. Decrease of uncertainty with the use of virtual laboratory modules

The second key sub-theme of this study was about the uncertainty that students experience when conducting a laboratory technique. Some participants (n = 3) mentioned that they do not feel adequately prepared for laboratory sessions although they read the scripts in advance. The video demonstrations were praised by the students, as they felt that having access to such a tool prior to a laboratory session, would visually show them what to do, not just verbally or textually. Participants reported that when they know what they are expected to do in the laboratory, they become more confident, independent, and less anxious. From the qualitative data, it was understood that students are sometimes uncertain and unsure of what to do inside the laboratory, leading to anxiety and pressure. The data also showed that it is very important for students to know what to expect:

> "*…a video like that if I watched that before I went into a lab and then like, went into the lab I'd be like, I'd feel pretty confident because you show me exactly what to do like someone else is doing it rather than just being told what to do. … if like, we got access to watch and stuff like that before going into a lab, like so we sort of know what to expect what to do*" – PP3
>
> "*Sometimes I have some questions. And it makes me a bit insecure, working independently. … Well some people are, for example, some people are anxious. So you may be, you know, like, get anxious, and I get anxious as well. So they might be uploaded before the session, even though that's what they're gonna do, you know, like, they might give him the confidence. And, you know, like, or, like, kind of, like, relief, relieve the pressure of them.*" – PP1
>
> "*And knowing you have a practical coming ahead. If you have the time to see just a small video to make sure you, you know what to expect when you go to the lab. Maybe gives you less anxiety, frustration, or like when you get into the lab sometimes and you're like, Oh, my God, what I'm doing now?*" – PP4

The views expressed by participants are generally in line with findings from previous research that have demonstrated that vLab resources enable students to obtain a conceptual framework of laboratory experiments, resulting in a positive learning experience [37,38]. This outcome may be linked to a reduction in uncertainty and an enhancement of students' confidence in the laboratory. As explained earlier, uncertainty is experienced when the brain does not have pre-determined outcomes about a given situation, resulting in gaps in the processing of information or decision making. Experiencing uncertainty can also bring discomfort to an individual [32]. Moreover, when an individual is pursuing a goal, which in this study would be students carrying out laboratory procedures, it is likely that anxiety will occur, if there are obstacles. In order to minimize uncertainty, an individual should be familiar with the given environment and be aware of responses to achieve their desired goal. Therefore, in order to minimize the uncertainty of students inside the laboratory, students should be familiar with the laboratory environment and the procedures [32]. In addition, uncertainty will also be decreased if students are aware of responses to achieve the end point of an experiment [32]. As reported by participants, the vLab module could be a valuable resource in reducing uncertainty when carrying out forensic techniques in the laboratory:

"… So I feel like that will make people to have like, Oh, I'm supposed to see… two type of the result … coming out … Because of … the colour of the test. Blood is not changing. … So it means that there are no blood present. … And if there's colour changing, that means the blood is present. So it shows like, what we suppose to meet with our result, and why is going to obtain the result?" – PP6.

In this study, most participants (n = 6) claimed that they would need less assistance and become more independent if they had watched a vLab demonstration before attending the in-person laboratory session. These views confirm that the vLab module could be effective in reducing uncertainty and raising the confidence of forensic science students in the laboratory [33]:

"*I feel like if I watched that, like before going to a lab, I wouldn't need as much assistance as I do now. … at the moment, I'm sort of like, oh, what do we do next? … what does that mean? Whereas if I could use that, then I would know already. I mean, I might need a bit of assistance, but I wouldn't need half as much probably because I know I'm doing I've seen what I need to do.*" – PP3

Considering all the findings derived from the interviews, it can be concluded that the use of vLab modules can enhance forensic science students' knowledge, confidence, and independence in the laboratory. The views expressed by the study participants suggest that the implementation of the vLab learning tool, as part of teaching practical skills in forensic science degrees, would be beneficial. Moreover, this study agrees with previous studies on the use of virtual laboratory demonstrations in other science degrees [11,34].

It was established that uncertainty in the laboratory seems to be a very important factor that impacts students' learning experience, affecting their anxiety levels, confidence, and independence in the laboratory. The findings in our research, in conjunction with previous research, suggest that a vLab module can reduce uncertainty through virtual demonstrations of the laboratory procedures before the attendance of in-person sessions. However, it is worth considering to what extent uncertainty should be reduced in the context of education. One could argue that sometimes uncertainty could bring a more enhanced learning experience, forcing students to figure out solutions on their own [21,32]. From a forensic science perspective, however, an inclusive vLab resource, as suggested in our findings, could improve students' knowledge and skills in terms of "how to perform" to specific standards by observing an expert carry out the technique. Illes *et al.* [40] found that the hands-on content of forensic courses is a key driver of student engagement. The use of inclusive vLab resources could enhance students' laboratory experience and promote student engagement and interest in forensic science in a diverse international cohort of students and in the post-COVID world [14,15,49,50].

4. Conclusion

Laboratory teaching methods have evolved throughout the years. Following the coronavirus pandemic, virtual laboratory resources have become popular as a learning tool for science degrees. This qualitative study aimed to examine the value of a vLab module in teaching forensic science practical techniques. Overall, our participants emphasised the need for a visual representation of laboratory scripts. We found that, when used in conjunction with in-person laboratory sessions, vLab modules could enhance the practical skills of forensic science students, while accommodating all different types of preferred learning styles (visual, auditory, and kinaesthetic), thereby promoting inclusivity among a diverse and multinational cohort. Although a vLab module cannot substitute face-to-face laboratory sessions, it was established that they could improve students' confidence, knowledge, and independence when carrying out forensic techniques. Our findings were consistent with other studies that have tested the use of video demonstrations in other university science degrees which show a positive attitude towards the implementation of this learning tool. Whilst the overall outcomes are positive, this study only interviewed forensic science students from only one university and further work should be considered for different universities nationally and internationally. A future study into the experience of students with reasonable adjustments may also inform the design and implementation of forensic vLabs. Additionally, future research into the relationship between the use of a vLab module and students' performance is recommended to confirm their perceived benefits.

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Aaron Opoku Amankwaa: Conceptualization, Methodology, Writing – review & editing, Supervision. **Viktoria Gjergo:** Methodology, Writing – original draft. **Sonya Hamagareb:** Conceptualization, Methodology, Writing – original draft.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scijus.2023.02.002.

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