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Using HistoGuide Mobile Application (Virtual Microscopy): A Qualitative Pilot Study on Usability and Sixth Form Students' Learning Experience

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Abstract

HistoGuide application is a smartphone application system used by sixth form students as virtual microscopy and slides to solve the problems of incorrect drawing and labelling, inability to apply magnification and scale, and inability to observe details in microscopic practical works. However, as a newly developed application, there are still many who do not understand the usability of the HistoGuide application. In building a good application, one important part is good usability. Usability testing, especially in the HistoGuide application, can show users' ease and efficiency in using the system. The authors try to use qualitative usability testing through observation, document analysis and interviews with four participants as a pilot study before a real study. The analysis revealed the preference of the students for utilizing virtual microscopy as an educational tool in terms of usability, in the construct of usefulness, ease of use, ease of learning, satisfaction, effectiveness and efficiency. These results indicate that the HistoGuide application is good. The results of usability measurement are expected to help the development and improvement of the HistoGuide application in the future, besides gauging the students' learning experience. The study also revealed that students accepted virtual microscopic learning tool that was easy to use, available at a distance, encouraged collaboration and mastery, changed learning attitudes and emulated the same concepts of optical microscopy. Although there are some concerns and challenges, the overall learning experiences are highly positive towards complementing optical microscopy with virtual microscopy.

Keywords: HistoGuide application, virtual microscopy and slides, usability, usability testing, learning experience

INTRODUCTION

During the Covid-19 pandemic, schools shifted to online teaching, which is also true in the case of Malaysia. Educators employed various teaching methods, including virtual microscopy, especially during the lockdown in replacement of laboratory work. However, during post-pandemic, these practices have continued, and thus, the students' manipulative skills (dexterity) acquirement has been an issue when it comes to laboratory work.

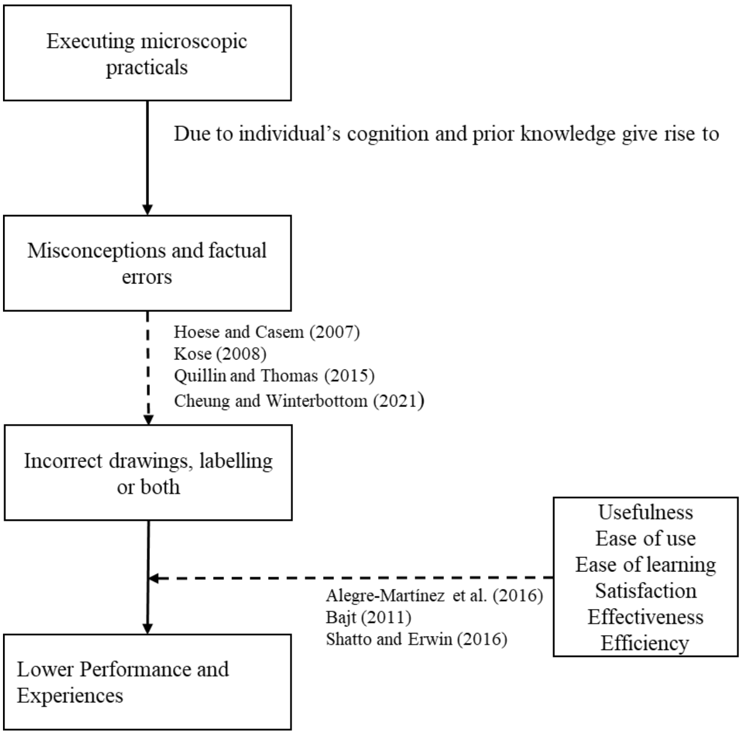
A comprehensive guideline is necessary to guide students in executing biology microscopic practicals in sixth form education (STPM/pre-university). Hence, a guide application is essential to help students draw and label precisely, besides applying magnification and scale, bearing in mind the usefulness, ease of use, ease of learning, satisfaction, effectiveness and efficiency of the application cause to the students. Besides improving the school-based assessment, the guide application usage is hoped to increase students' confidence level and motivation in executing the microscopic practicals. However, there is a lack of comprehensive guidelines for after-secondary education in Malaysia, especially for STPM/pre-university.

LITERATURE REVIEW

Preliminary findings from one of the sixth form centres showed that 68.8% of students scored below five marks in the results section of the school-based assessment. Drawing, labelling, and applying magnification and scales encompass about 40.0% of the marks allocated in the single assessment, which consisted of manipulative skills (A), results (B), discussion (C), and conclusion (D). Students are found to be weak in drawing, labelling and applying magnification and scales. Only 9.4% of students scored full marks in the results section (B), emphasizing drawing and labelling. The findings were supported by [1], which explored students' visualization competence and found that they are weak in perceiving microscopic entities through drawing and labelling. They reported that 60.0% of the students could not label their biological drawings, and a higher proportion of students tend to give fewer labels [1].

The incorrect drawings, labelling or both are identified as the observable symptoms of the problem. [2] mentioned that teachers could gather large amounts of data on students' mental models of scientific concepts using microscopic drawings. The drawings are used to determine conceptual understanding and misconceptions [3]. Drawing exposes misconceptions [4]. The researchers gave samples of references that reveal misconceptions through drawings. These incorrect drawings and labelling or both will decrease performance and learning experiences when executing practicals, as shown in Figure 2.1. It is due to the inability of students to draw and label, apply magnification and scale and observe details as there is a lack of quality images for practicals [5].

Figure 2.1 Symptoms/Issues Arise during the Execution of Microscopic Practicals



Thus, from the literature review of selected studies in histology, it can be concluded that virtual microscopy and slides address the mentioned students' inabilities, as suggested by [6]. Students are constantly looking to employ digital technology in their learning [7]. Students wanted dynamic, participatory, and meaningful learning incorporating observation and practice [8]. The technology employed has usability constructs of usefulness, ease of use, ease of learning, satisfaction, effectiveness and efficiency, as [9] and [10] suggested.

Besides that, from previous research, researchers found that besides students' inability to make good drawings, students cannot draw to scale and observe details [11], [12]. In addition, [5] explored difficulties students face in learning histology and plant anatomy. According to students, the challenges emerged due to the topic's nature, understanding the terminologies utilized, and insufficient instructional time. There aren't enough quality images to help students draw and label in the microscopic practicals [5]. Students, therefore, aren't able to observe details.

Based on past research before 2010, teachers employed interactive virtual microscopy slides, a more novel and efficient tool for improving histology learning [13]–[16]. Then, more educators have moved to a computer-based virtual learning approach to histology teaching to save time, money and laboratory space [17]. However, many educators have emphasized using microscopes and glass slides to learn histology properly. The ideal or optimal alternative in histology teaching would be an active learning approach [18] that melds microscope-based learning strategy with computer-based learning tools [14], [19], [20].

[21] mentioned that students use virtual microscopy as self-directed learning, further supported by [22] research. Students must be prepared for the microscopic laboratory practicals. There are many benefits from previous studies in the medical and dental fields regarding virtual microscopy [13], [14], [19], [23]–[27]. These quantitative studies have focused on the ability to improve grades and measure outcomes based on these modern technologies. However, there are insufficient studies of virtual microscopy and slides in the Malaysian secondary school context on learning experiences. Most of the studies are on academic performance and/or motivation aspects [13], [14], [19], [23]–[27].

Hence, this interview-based qualitative study aimed to test the usability of virtual microscopy and identify and explain students' learning experiences as they were introduced to virtual microscopy (HistoGuide application) and whether this technology altered their learning experiences. Hence, all the mentioned elements will be incorporated into the HistoGuide application for this study. Usability testing using the constructs from [9] and [10] will be employed as a follow-up to their study. Usability is referred to the constructs of usefulness, ease of use, ease of learning, satisfaction, effectiveness, and efficiency, as shown in Figure 2.2. User satisfaction is one of the important usability measures in studying the perceived success of any module or application. The sample of the HistoGuide application is shown in Figure 2.3.

Research Objectives:

1. To explore whether the optical microscopy and HistoGuide application (virtual microscopy and slides) are usable.
2. To explore students' learning experiences when introduced to virtual microscopy.

Research Questions:

1. Are optical microscopy and virtual microscopy usable? In terms of: a) usefulness, b) ease of use, c) ease of learning, d) satisfaction, e) effectiveness, and f) efficiency.
2. What are students' learning experiences when introduced to virtual microscopy?
    a) What are the most important factors that influence students' experiences when required to use virtual microscopy?
    b) How would students describe the use of virtual microscopy?
    c) What are the problems faced by students while using virtual microscopy?

Figure 2.2 Conceptual Framework of Study

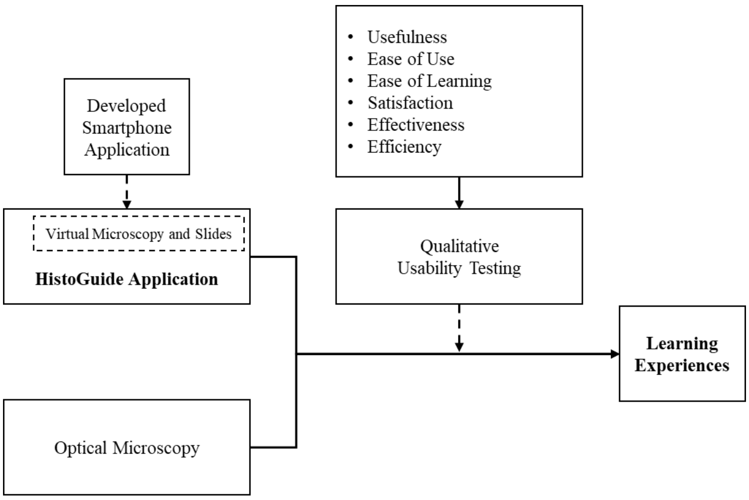
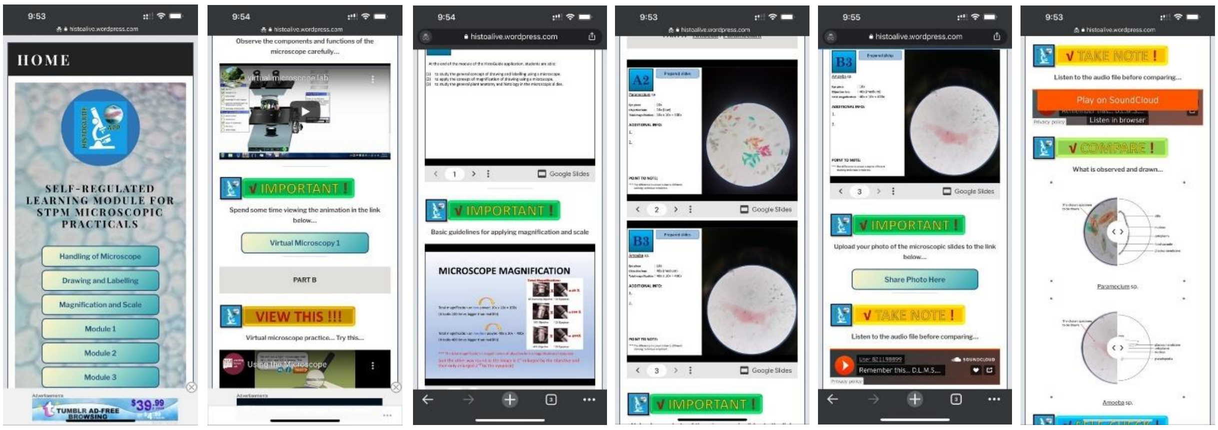


Figure 2.3 Samples of HistoGuide Application



METHODOLOGY

The study used a qualitative research design with observation, document analysis and interview methods. Each participant was asked about their experiences with virtual microscopy and optical microscopy. According to [28], qualitative research investigates and comprehends individuals or groups' meanings ascribed to a social or human situation. The case study focuses on capturing learning experiences with virtual microscopy in the sixth form curriculum. The research is not used to generalize into a population.

The target population selected for this study was sixth form biology (STPM/pre-university) students for the year 2022/2023. A target population is a group that includes individuals or objects in which a researcher is interested in drawing conclusions from a study. The sample, which is a smaller portion or representation of the population, consisted of four sixth form biology students in Kuala Lumpur through purposive sampling.

There are three instruments employed in this study. For the observation techniques, a checklist is created. It acts as a guide for the researcher during the observation of the participants for task completion. As for the document analysis techniques, a checklist is also created. It acts as a guide for the researcher during the document analysis. Three documents are identified. They are the written report using optical microscopy, written report using optical microscopy and ministry past practical report (964/5).

It is followed by the interviewing methodology, which allows the researcher to draft the interview questions while taking charge of the interview. For this study, unstructured interview sessions will be employed. With the help of a series of probing guiding questions developed and peer-reviewed with a panel of experts in science and education who are very familiar with developing qualitative research questions. The probing questions were examined to ensure alignment with the study and avoid any leading questions. It also guides the researcher in fulfilling all the usability testing constructs.

Validity and Reliability

Validity and reliability studies were conducted to analyse the qualitative data in the research. In trustworthiness, four criteria must be fulfilled [29]. They are credibility, transferability, dependability and confirmability. Investigator triangulation was conducted to ensure the research's internal validity (credibility). In this pilot study, three researchers participated in the data collection, analysis, and interpretation processes to ensure the data analysis's internal validity [30]. Detailed descriptions were made to ensure the research's external validity (transferability), categories organized the data, and direct quotations were used. In addition, using purposeful sampling strategies in the research contributed to external validity [30].

The pilot test study was conducted for reliability to ensure that the interview questions used in the study would validate the data collected. The proposed interview questions were shared with a small number of people with extensive experience with the subject and population of the study. The researcher selected two science experts in histology or plant anatomy from UPSI. The responsibility of the expert panel included

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revising and analysing the proposed interview questions and identifying their adequacy for collecting the data needed for the study. The expert panel agreed that the probing questions were appropriate for the study and provided suggestions for rephrasing the questions to maximize the data collection.

Then, two more experts from the education background in the Faculty of Science and Mathematics with experience in research interview questions were used to review the proposed questions and verify that the questions aligned with a qualitative study of this nature. The objective of having a researcher review the interview questions assured the suitability of the probing questions that guided the interview process. The additional expert is to agree that the questions were fair questions designed to collect the learning experiences' data and add credibility to the study in terms of dependability. The experts' review was evaluated using the Cohen kappa's index and rated very good. The Cohen kappa is 1.00 (for observation checklist, document analysis checklist, and interview constructs guide), and according to Cohen (1960), Cohen's kappa coefficient, $\kappa > 0.81$, showed a very good agreement between the raters. Since Cohen's kappa coefficient is greater than 0.81, the instruments developed are valid to be used to test the usability of the HistoGuide application and learning experiences.

The transcriber (one of the researchers, cross-checking) is employed during data analysis for confirmability. Then, each transcribed interview was delivered to each participant for member-checking to establish the credibility and validity of the interviews in terms of confirmability. The accuracy process was more guided toward the transcription submitted, ensuring reliable data. The transcriber completed the corrections and returned them to the researcher for completion of the data analysis. Each transcribed interview was read several times for dependability, and common themes were constructed for final analysis and interpretation.

Throughout the whole data analysis, the researchers employed self-reflections for the dependability of the research. The coding methods are consistent with specific keywords throughout the whole research procedure. The researchers employ a reflective memo to get the whole picture of the research in the end finally. Improvements for coding and theme classification are made after discussions among the researchers.

DATA ANALYSIS

Each participant returned the transcribed interview to the researcher, and none requested any correction. The accuracy process was more guided toward the transcription submitted, ensuring reliable data. According to [31], even the most proficient transcriber misses a word or two or transcribes slightly different phrases from what was actually said. Each transcribed interview was read several times, and common themes were identified for final analysis and interpretation.

The first part of the interview explored the participants' learning experiences as users of optical microscopy in their laboratory practical works. Participants were asked questions about the challenges and conformity with optical microscopy and any experience or knowledge about virtual microscopy. Although different participants answered the same set of questions, their answers followed a similar degree. For example, when asked about the challenges with light microscopy, participant 01 stated, *"I have problem focusing the specimens… I'm not capable in focusing. And it's so difficult to identify the organisms and the structures.,"* while participant 03 stated, *"Specimen focusing, finding the specimen and… use correct objective lenses."* These quotes and other summarized quotes will be notated throughout the presentation of the data.

Table 4.1 summarises the main questions of the first part of the interview regarding challenges with optical microscopy, the rating of proficiency with optical microscopy and knowledge of digital or virtual microscopy (source).

Table 4.1 First Part of the Interview Summary on Optical Microscopy

Participant Coding	Challenges Faced with Optical Microscopy (**Usefulness**)	Rating of Proficiency (**Effectiveness**)	Knowledge of Virtual Microscopy
01	• Focusing • Specimen Identification	3	None
02	• Specimen Identification	4.2	Limited
03	• Focusing • Specimen Location • Objectives	4	Limited
04	• Focusing	4	Literature

The second part of the interview explored the participants' learning experiences as they evaluated specimen samples through virtual technology. These interviews were conducted a week after the optical microscopy. The second interview's focus included the advantages of virtual microscopy adding to their learning experience. Table 4.2 summarises the main questions of the second part of the interview, including virtual microscopy learning experience, advantages of virtual microscopy, virtual microscopy in the curriculum, and the one word or sentence that describes virtual microscopy.

Table 4.2 Second Part of the Interview Summary

Participant Coding	VM Learning Experience (**Usefulness**)	Advantages of VM (**Ease of Use**)	VM in curriculum	One word or Sentence Description of VM (**Satisfaction**)
01	Fantastic, clear image differentiation	Accessible everywhere 24/7	Provision of sharing images with classmates and working at own pace	Cool
02	Different and awesome	Remote view and sharing of images	Future of biology laboratory and great learning tool	Awesome, fantastic and sharable
03	Learning at a technological level	Recall and label (annotate)	Reaches the teaching structure of online education	Fantastic
04	Amazing, learning at different level	Image comments, synchronized studies	Value to the curriculum, flexible working at a distance	Amazing to evaluate and study live images remotely

According to [32], existing coding categories can be modified; new categories can be created, while old categories can be discarded. A manually driven analytical scheme was created to further summarize the codes and categories into units that could be manageable and interpretive. Table 4.3 represents the coding employed for the three data analysis methods.

Table 4.3 Coding Employed, Representation and Example

Coding Employed	Representation	Example
P4/OB/OMA1	Participant 04 / Observation / OMA1	Participant 04 is able to draw and label using optical microscopy (OM)
P1/OB/VMA7	Participant 01 / Observation / VMA7	*"So troublesome, scrolling…"*
P1/DA/OMA1	Participant 01 / Document Analysis / OMA1	Participant 01 is able to draw and label using optical microscopy (OM)
P1/DA/VMP1	Participant 01 / Document Analysis / VMP1	Participant 01 is able to draw and label using virtual microscopy (VM)
P4/IN/OMC1	Participant 04 / Interview / OME2	*"All good so far."*
P4/IN/VME1	Participant 04 / Interview / VME1	*"Amazing"*

Table 4.4 represents the themes categorized with subcategorized that were extracted from the multiple reviews of the transcribed first and second parts of the interviews related to light and virtual microscopy.

Table 4.4 Themes and Categories from Transcribed Interviews with Coding Used

Optical Microscopy	Coding Used	Virtual Microscopy	Coding Used
Challenges of Optical Microscopy		Advantages (A) / Disadvantages (D) of Virtual Microscopy	
• Focusing	OMC1	• Distance Learning (A)	VMA1
• Specimen identification and structural details	OMC2	• Asynchronous Learning (A)	VMA2
• Objective selections	OMC3	• Automated Focusing (A)	VMA3
• Feeling incompetent	OMC4	• Collaborative learning (sharing) (A)	VMA4
• Sharing microscope	OMC5	• Feature Driven (A)	VMA5
		• Replace Optical Microscopy (D)	VMA6
		• Challenging (D)	VMA7
		Interactive Expressions	
Knowledge Base of Optical Microscopy		• Future of Biology Education	VMI1
• Proficiency Scale between 3 and 4	OMP1	• Excellent Details of Specimens	VMI2
• Mastering of Biological Material (microscope and slides)	OMP2	• Peer Review (comments)	VMI3
		Lack of Dexterity and Microscopic Skills	
Learning Experience with Optical Microscopy		• Dexterity is Maintained	VMD1
• Hands-on Mastering and Dexterity	OME1	• Concerns	VMD2
• Positive Experience	OME2	Competency Measures in Laboratory Education	
• Negative but Manageable	OME3	• Mastering of Subjects (as a whole)	VMM1
		Learning Experience with Virtual Microscopy	
		• Positive Experience	VME1
		• Collaboration with Peers (complete tasks together)	VME2
		• Increased in Mastering and Visualization Learning (drawing & labelling, learning)	VME3

Presentation of Data and Results of the Analysis

The first part of the study was on qualitative usability testing, with four participants (N=4) answering the first main research question. Usability testing was guided and measured by the criteria a) usefulness, b) ease of use, c) ease of learning, d) satisfaction, e) effectiveness and f) efficiency, as shown in Table 4.13.

In the constructs of usefulness, the students are able to complete the task based on the stated criteria in the observation checklists using virtual microscopy. Some students faced difficulty focusing and using the correct objectives in optical microscopy. From observations, participants 1, 3 and 4 were unable to focus [OB/OMC1], while one of the participants was unable to use the correct objectives [P3/OB/OMC3]. From the interview, it is found that the participants have the mentioned difficulties.

"I have problem focusing the specimens…" [P1/IN/OMC1]
"I'm not capable in focusing." [P1/IN/OMC4]
"Specimen focusing." [P3/IN/OMC1]
"Use correct lenses, I meant objective lenses." [P3/IN/OMC3]

As for ease of use, a lot of guidance is still needed by the participants in optical microscopy, whether from friends or teachers during the observation. However, noticeably, less guidance is needed in virtual microscopy. From the interview, it is found that the participants have guidance from various sources.

"… I will ask my friend or teacher." [P1/IN]
"… Internet, Campbell, Sasbadi." [P4/IN]

As for the incidents (constructs of ease of learning) during observation for task completion, one of the major incidents observed during the pilot study was participants visibly seen lost very often in the HistoGuide application (virtual microscopy), so they needed a lot of careful scrolling to locate the right information on the small screen. The fact that they said something clearly negative about the scrolling as they experienced. There were a few occasions when participants mentioned among themselves that viewing the HistoGuide application on mobile is an interestingly good idea.

"So troublesome, scrolling…" [P1/OB/VMA7]
"The app is interesting, a good idea" [P4/OB/VME1]

As for the perceptions of satisfaction, either virtual or optical microscopy, the participants have mixed reviews on whether they are satisfied using the said microscopy technique. Noticeably, based on Table 4.13, the students are relatively more satisfied with using virtual microscopy. However, gauging learning experiences through observation using these perceptions of satisfaction is simple. Hence, not enough data can be generated. Thus, another method of qualitative measure through interviews is also employed. From the interview, it is found that the participants are relatively satisfied.

"Cool." [P1/IN/VME1]
"Awesome, fantastic, sharable." [P2/IN/VME1]
"Fantastic." [P3/IN/VME1]
"Amazing." [P4/IN/VME1]

All four participants successfully completed the task under effectiveness constructs, although sophistication and efficiency varied between participants. Noticeably, from the observation, three participants needed guidance and consultation from their teacher or friends to complete the tasks using optical microscopy. Whereas, for virtual microscopy, only one participant needed help from friends, as mentioned in the interview.

"… I will ask my friend or teacher." [P1/IN]

Besides that, in the efficiency construct, it is also noticeable that the participants recorded an earlier time to complete the task with virtual microscopy before the lesson ended (40 minutes).

The pilot study was also completed with document analysis from the four participants (N = 4). Three documents were analysed; a) report using OM, b) report using VM, and c) annual ministry reports for practical exams. Triangulation of data is based on observation, document analysis and interview. The document analysis, preceded by an interview, enables researchers to get in-depth data to explore the written data further. For example, in participant 03, although she got everything correct for the written report, the researcher had doubts, but based on the researcher's observation and document analysis, further investigation was taken. The researcher identified that participant 03 could not focus on the specimens and employed the correct objective lenses during observation [P3/OB/OM]. However, the participant scored full marks for the written report [P3/DA/OM]. Hence, from the document analysis, the researcher found a lot of corrections done to her written report. Thus, further exploration through the interview was employed by the researcher. It was found that the participant had received help from her friends when submitting the written report. Thus, although the students' written report was perfect, it did not mean that the students were able to do so. Table 4.5 depicted a part of the interview transcription concerning the mentioned issues.

Table 4.5 Part of Interview Transcription for Participant 03

007	R:	Based on the report you submitted as your school-based assessment, it is found that you are actually quite good with the assessment [P3/DA/OM]. Any problems faced?
008	P:	*"Sorry, I actually able to do it because my friends help me."*
009	R:	What do you mean by that?
010	P:	*"Erm…"*
011	R:	No worries, you can tell me, this is private between me and you. Your teacher won't know any of these. I observed your school-based assessment [P3/DA/OM], there are a lot of corrections done by you until your paper is full of liquid paper.
012	P:	*"Yeah, I actually copied from my friend, cause I don't know how to calculate. They help calculate for me."*
013	R:	Oh, I see… Then for the focusing, I can see you in class using optical microscopy, you refer to your friends a lot? When I observe you in class…

In summary, three subquestions were employed in answering the second main research question. Table 4.6 illustrates a relation between the research questions and the identified themes from the data collected from the participants during the interviews. While Table 4.7 describes the summary of the qualitative data enumeration in quantifying qualitative data.

Table 4.6 Research Questions and Identified Themes from Data

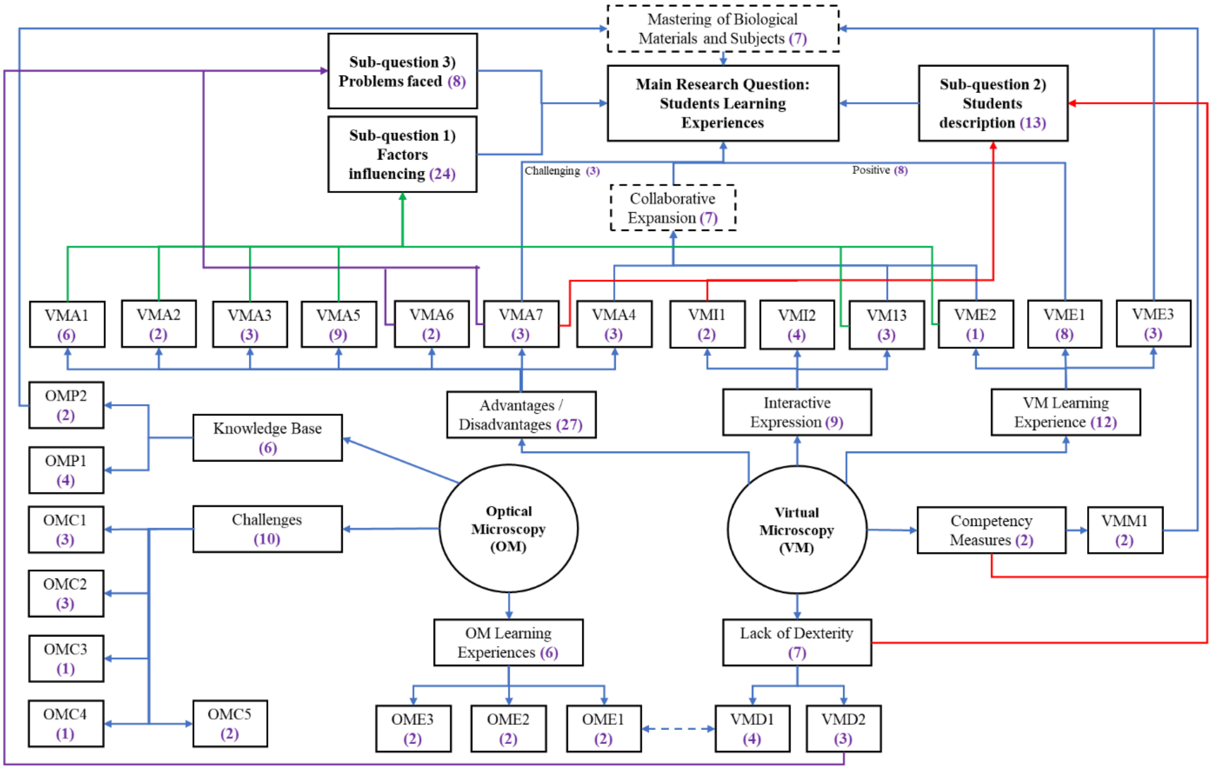
Research Questions:	Themes from Data:
What are students' learning experiences when introduced to virtual microscopy?	• Positive but Challenging • Collaborative Expansion • Mastering of Biological Material and Subjects
What are the most important factors that influence students' experiences when required to use virtual microscopy?	• Distance Learning • Asynchronous Learning • Automated Focusing • Collaborative Learning • Feature Driven • Peer Review
How would students describe the use of virtual microscopy?	• Challenging • Lack of Dexterity and Microscopic Skills • Future of Biology Education • Competency Measure in Laboratory Education
What are the problems faced by students while using virtual microscopy?	• Disadvantages of Virtual Microscopy • Concerns

Table 4.7 Summary of the Qualitative Data Enumeration

Theme	SubTheme	Number of Statements					
		Codes	1	2	3	4	Total
Challenges of Optical Microscopy	Focusing	OMC1	I		I	I	3
	Specimen identification and structural details	OMC2	I	I	I		3
	Objective selections	OMC3			I		1
	Feeling incompetent	OMC4	I				1
	Sharing microscope	OMC5		I		I	2
Knowledge Base of Optical Microscopy	Proficiency Scale between 3 and 4	OMP1	I	I	I	I	4
	Mastering of Biological Material (microscope and slides)	OMP2		I		I	2
Learning Experience with Optical Microscopy	Hands-on Mastering and Dexterity	OME1			I	I	2
	Positive Experience	OME2		I		I	2
	Negative but Manageable	OME3	I		I		2
Advantages (A) / Disadvantages (D) of Virtual Microscopy	Distance Learning (A)	VMA1	I	II		III	6
	Asynchronous Learning (A)	VMA2		I	I		2
	Automated Focusing (A)	VMA3		I	I	I	3
	Collaborative learning (sharing) (A)	VMA4	I	I		I	3
	Feature Driven (A)	VMA5	I	III	II	III	9
	Replace Optical Microscopy (D)	VMA6	I		I		2
	Challenging (D)	VMA7	II			I	3
Interactive Expressions	Future of Biology Education	VMI1		I	I		2
	Excellent Details of Specimens	VMI2	I	I	I	I	4
	Peer Review (comments)	VMI3				III	3
Lack of Dexterity and Microscopic Skills	Dexterity is Maintained	VMD1	I	I	I	I	4
	Concerns	VMD2		II		I	3
Competency Measures in Laboratory Education	Mastering of Subjects (as a whole)	VMM 1				II	2
Learning Experience with Virtual Microscopy	Positive Experience	VME1	II	III	I	II	8
	Collaboration with Peers (complete tasks together)	VME2				I	1
	Increased in Mastering and Visualization Learning (drawing & labelling, learning)	VME3		I		II	3

In data presentation, some researchers illustrated a relationship among code categories and themes to display a clearer and bigger picture of the event under study [33], as shown in Figure 4.1.

Figure 4.1 A Network Diagram in Presenting Data



All participants expressed that their learning experience using virtual microscopy was positive, and eventually, virtual microscopy will be incorporated into biology education. In the current curriculum, students receive their microscopy training through optical microscopy, which in many instances, it has been introduced in the science or biology courses of high school. The consensus from the participants views virtual microscopy as the ultimate alternative to optical microscopy, as education expands its horizons through distance learning and asynchronous learning. The participants welcomed the opportunity of a transitional microscopy experience and supported a curriculum change that included microscopic technology. They expressed that virtual microscopy is advantageous in mastering students' skills, establishing peer collaboration and providing learning at a distance. However, half of the participants expressed continuing the current microscopy instructions and adding virtual microscopy as an add-on to the laboratory microscopic practicals.

DISCUSSION

Observation techniques were employed to observe participants using an observation checklist. The items in the observation checklist were derived from the research question posed for the study. All items were peer-reviewed by experts in the biology and biology education field. Each item allowed the researcher and participants to assess their satisfaction with microscopy in their sixth form microscopic practicals. The goal of the items and the observation techniques was to explore the usability of optical microscopy and virtual microscopy and consequently answer the first main research question; are optical microscopy and virtual microscopy usable? In terms of: a) usefulness, b) ease of use, c) ease of learning, d) satisfaction, e) effectiveness and e) efficiency. All four participants are generally positive and satisfied with virtual microscopy in the sixth form microscopic practical, compared to optical microscopy (N=4).

Document analysis was employed for data triangulation. The items in the document analysis checklist were derived from the research question posed for the study. All items were peer-reviewed by experts in the biology and biology education field. Each item allowed the researcher and participants to assess their effectiveness with microscopy in their sixth form microscopic practicals. The document analysis, preceded by an interview, enables researchers to get in-depth data to explore the written data further. The researcher identified that one of the participants could not focus on the specimens and employed the correct objective lenses during the observation [P3/OB/OM]. However, that participant scored full marks for the written report [P3/DA/OM]. Hence, from the document analysis, the researcher found many liquid paper corrections to the written report. Thus, the researcher employed further exploration through the interview, and it was found that participants had received help from their friends when submitting the written report. Although the students' written report was perfect, it did not mean they could achieve the intended learning outcomes.

Meanwhile, the questions asked of the participants during the unstructured interviews were derived from the second main research question and additional research subquestions posed for the study. All questions were peer-reviewed by experts in the biology and biology education field. Each interview question allowed the researcher and participants to assess their proficiency, knowledge, and learning experiences with microscopy in their sixth form microscopic practicals. The goal of the interviews was to interact and experience the learning mechanisms of virtual microscopy and consequently answer the second main research question; what are students' learning experiences when introduced to virtual? All four participants agreed that the use of virtual microscopy in the sixth form microscopic practical was positive and for the future of education, enhancing the learning experiences of their learners through collaboration and material mastering via asynchronous and distance learning (N=4).

Participants agreed that optical microscopy should continue to be part of the laboratory microscopic practicals based on microscopy functionality but not be considered the total methodology of microscopy instruction. Although microscopy dexterity (manipulative skills) was a concern with the introduction of virtual microscopy, only two out of four participants were concerned with a loss of dexterity (50.0%). However, the remaining two participants did not see a problem with microscopy dexterity since dexterity is used in some form during virtual microscopy.

Following the learning experiences of each participant, all participants (100.0%) expressed that virtual microscopy made a difference in their learning and solved their problems in microscopic drawing and labelling besides applying magnifications and observing details in reviewing slides. Students review slides in a conventional laboratory setting within a face-to-face laboratory and highly individualised sixth form microscopic practical. It is almost impossible to provide instruction of this nature in a distance learning format due to the preparation of slides and microscope availability for each student.

Students develop unique ways of mastering a subject and consider various alternatives to achieve that mastery. 25.0% of the participants, or one of the four, stressed the importance of easily mastering a subject of tissue identification via instruction with virtual microscopy compared to optical microscopy. Although the learning experiences were combined with learning tools and the actual experiences in the subject matter, the goal was to incorporate the virtual microscopy learning environment in terms of usability. However, the study demonstrated that students seek virtual microscopy as the alternative to microscopy instruction that delivers at a distance, with a mastering perception that includes classmates and teachers collaborating in successful learning.

Conclusion Based on the Results

There is limited research on students' learning experiences in sixth form laboratory practicals using virtual microscopy as a learning tool. However, many research studies support virtual microscopy as an essential educational concept in the classroom and learning in undergraduate studies. This study provides positive outcomes for students utilizing virtual microscopy to identify organisms and cells, labelling, applying magnification and scale, and observing details. The implementation of virtual microscopy in sixth form biology education can successfully improve the students' confidence through their mastery learning experience, which eventually can measure their knowledge of the laboratory science subjects in preparation for pursuing their tertiary education.

Comparison of Findings with Previous Literature

Participants of the study supported the inclusion of virtual microscopy in sixth form microscopic practicals that utilized microscopy as a means of tissue, cells and organism identification for assessment purposes. Microscopy has been an important learning tool in sixth form biology education as students experience the mastery of concepts in identification. Participants supported the statements from [34] regarding education from glass slides and optical microscopy transitioning to various settings, including substituting multiheaded sessions, multisite conferences, publications, proficiency testing, telehealth, and e-education. Although microscopy dexterity was concerned, participants did not reflect a concern since manual manipulation of a virtual microscope is still necessary. However, they did express that optical microscopy should continue to be part of the curriculum, complemented with virtual microscopy for training purposes. [35] presented similar findings, where students accepted optical microscopy as a supplementary learning tool [14], [19], [20]. Currently, sixth form microscopic practicals are designed to evaluate each specimen for identification and analysis through the physical mastery of optical microscopy.

The interview found that some participants had received help from their friends when submitting the written report as a school-based assessment. Although the students' written report was perfect, it did not mean they could achieve the intended learning outcomes. [36] highlighted the key concerns in school-based assessment for practical work regarding the impact on student learning and fairness of the school-based assessment. Meanwhile, [37] mentioned that teachers tend to accept correct answers only as experiments carried out with due diligence procedures will result in correct answers because experiments cannot fail. Hence, the students will provide correct answers although they could not achieve the intended learning outcomes.

As part of the study, comments regarding the advantages of virtual microscopy becoming an integral part of the sixth form microscopic practicals were sought. These advantages addressed the concepts of distance and collaborative learning. Additionally, the participants felt strongly about their learning experiences with virtual microscopy and recommended including it in sixth form education through their interviews. Although the study was focused on learning experiences with microscopy, the spectrum of learning experiences ranged from enhanced learning to the future of education (Table 4.6 and Table 4.7).

Interpretation of the Findings

Virtual microscopy in laboratory practicals initiates a greater understanding of microscopic morphology based on learning experiences [38]. The participants preferred virtual microscopy to enhance learning and microscopic training. The participants also explained that virtual microscopy provided a provision of quality image sharing with classmates in live mode and the ability to work at their own pace.

Therefore, prior research suggesting virtual microscopy for education and training in laboratory practicals confirms the findings from the learning experiences that this technological advancement for the identification of microscopic structures, cells, and organisms enhances the learning and mastery of microscopy techniques [34]. In addition, the findings revealed the importance of collaboration at a distance with virtual microscopy as the instructional tool. For example, the participants mentioned the importance of live discussions and consultations on images and annotations.

Therefore, [39] was right in concluding that students recognize and appreciate the benefits of virtual microscopy in laboratory settings, allowing instructors to create an optimal educational environment that satisfies students and promotes their learning. The participants were involved in evaluating scanned glass slides and identifying microscopic structures and cells at different magnifications using a viewing software that emulates an optical microscope, exploring their learning experiences that differ from their current learning methodology. It aligns with the research by [40] that cited how students felt about studying microscopic pathology using virtual slides. Furthermore, in the quantitative study, [39] demonstrated that survey responses from students that viewed lab slides through digital microscopy showed more positivity toward learning than those completing the same task through optical microscopy. The participants mentioned the expansion of mastering learning, value to curriculum, flexibility, and working at a distance as important considerations when learning microscopy virtually. [41] study identified students' agreement with virtual microscopy as a positive learning tool for the material. A study by Hande et al. measured student satisfaction using optical, virtual, and optical and virtual microscopes [22]. The study showed a high degree of satisfaction (87.6%) toward virtual microscope usage [22].

The most challenging portion of implementing virtual microscopy in teaching laboratory science courses is to do so without neglecting optical microscopy as an essential learning tool [42]. The participants stated that although virtual microscopy was the future of biology education, optical microscopy should continue to be part of the curriculum. The study indicated from the participants' learning experience that viewing microscopic images via virtual microscopy superseded the evaluation of microscopic samples of those studied under optical microscopy. The study reveals that the automation and simplicity of image focusing, quality, and ease of use prompted a positive learning experience to include virtual microscopy. The research suggests that virtual microscopy offers tremendous benefits [43]. Offering virtual microscopy as a learning tool in biology is the frontier of science education and a critical concept of mastery and learning of microscopic techniques.

Several other studies explored students' opinions toward the use of virtual microscopy. Overall, these studies reported several advantages of using a virtual microscope as a learning tool, namely easy navigation with optimum contrast, clear images, presence of interactive features that allow collaborative learning and easy access to virtual microscopy for self-regulated study [42], [44]–[48]. However, it should be noted that some students and educators had also indicated a strong preference for the continued use of traditional microscopy, supplemented with virtual microscopy, as both tools in adjunct optimized students' learning [49], [50].

Another issue regarding the student's actual ability is acquiring the skills needed in optical microscopy. Using data triangulation, this study identified the student's inability to draw and label, apply magnification and scale and observe detail. The issue regarding values and truthfulness when reporting has been unresolved in the school-based assessment [51]. Ultimately, virtual microscopy complementing optical microscopy can solve the mentioned problems based on usability testing and students learning experiences.

Limitations

This qualitative study was limited to four participants in a sixth form centre in Kuala Lumpur, Malaysia. Therefore, the learning experiences obtained from this study cannot be applied to all sixth form biology that explored virtual microscopy as a learning tool. In addition, this study avoided focusing on any quantitative values that report improvement in exam scores or grade improvement and motivation due to the interaction with virtual microscopy. Besides, the study focused entirely on capturing students' learning experiences in evaluating and identifying tissue structures and cells without focusing on one specific learning experience outcome.

The assumptions presented in this study were: (a) virtual microscopy will influence the way that students perceive laboratory activities; (b) the students will be able to narrate their experiences regarding the learning aspect of virtual microscopy; (c) the sample selected is representative and adequate; (d) the questions selected for the interview are appropriate, direct, and will yield meaningful information; and (e) the researcher maintains neutrality on teaching with digital or virtual technology. Lastly, the study's limitations included internet availability in schools. Students will find it inconvenient to use virtual microscopy when interpretation is obtained from cloud-based security systems.

Suggestions for Further Research

This study adds to the body of research on sharing the life experiences of sixth form biology students during the implementation of virtual microscopy as an educational learning tool in microscopic techniques. It can be replicated by having future researchers expand the number of students included. In addition, researchers might study the learning experiences of students enrolled in matriculation colleges (another mode of pre-university education in Malaysia), as the same syllabus is involved. Further research should require a larger population. Furthermore, a study using both qualitative and quantitative methodologies to compare learning experiences and their performance (i.e., grade or exam scores) or motivations based on their learned experiences will help evaluate the positive effects of virtual microscopy in the curriculum.

CONCLUSION

Optical microscopy is one of the most important learning skills for future biology laboratorians and microscopic instruction's golden standard. However, the virtual microscopy technique has evolved through the years, maintaining with technological advances in the biology field. [38] confirmed the evolvement of digital pathology as technology advances. The driving force behind this study was supporting technological advances and preparing future sixth form biology education learners to adapt to microscopic advances. Four students were interviewed using an unstructured interview process, besides the observation and document analysis techniques, to understand students' learning experiences when exposed to virtual microscopy.

Analysis of the collected data revealed the preference of the students for utilizing virtual microscopy as an educational tool in terms of usability, in the construct of usefulness, ease of use, ease of learning, satisfaction, effectiveness and efficiency. This study also revealed that students accepted a microscopic learning tool that was easy to use, available at a distance, encouraged collaboration and mastery, changed learning attitudes and emulated the same concepts of optical microscopy. Although there are some concerns and challenges, the overall learning experiences are highly positive towards complementing optical microscopy with virtual microscopy.

CONFLICT OF INTEREST

The authors confirm that the information provided in the article does not contain a conflict of interest.

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