Supporting Microscopy Learning with Ocul-AR, a Virtual and Augmented Reality-Powered Mobile Application

Joanna W. Pylvänäinen[1,4], Laura Mairinoja[2], Tino Tuomisto[2,3], Junel Solis[1], Diana M. Toivola[4,5*] and Pasi Kankaanpää[1*]

[1] *Turku BioImaging, University of Turku and Åbo Akademi University, Tykistökatu 6B, 20520 Turku, Finland*
[2] *Institute of Biomedicine, University of Turku, FI-20014 University of Turku, Turku, Finland*
[3] *Turku University of Applied Sciences, Joukahaisenkatu 3, 20520 Turku*
[4] *Department of Biosciences, Cell Biology, Åbo Akademi University, Domkyrkotorget 2, 20500, Turku, Finland*
[5] *InFLAMES Research Flagship Center, University of Turku and Åbo Akademi University, Turku, Finland*

Abstract

Microscopy has become an irreplaceable tool for visualizing, analyzing and quantifying life in several research fields, such as cell biology and tissue diagnostics. However, to acquire optimal imaging of a sample, the microscope needs to be correctly operated. While microscopes are available in many research institutions and laboratories, they often lack proper user and calibration instructions. Online training materials have become important, but their content is usually generic, microscope-specific information is unavailable, and they cannot help users on-site. Therefore, specific microscopy skills are normally transferred from person to person, which in turn leaves space for subjective errors that can accumulate over time. To meet these challenges, we developed a mobile application, Ocul-AR, for microscopy teaching and support. Ocul-AR was designed by a multidisciplinary team to guide microscopy students and users to learn about microscopy, optimize light paths and operate light microscopes independently. To investigate the usability and relevance of the application in higher education, a voluntary test group was collected from a university introductory-level microscopy course, and the Ocul-AR application was tested in separate sessions during and after the guided hands-on training of the course. Volunteers were surveyed about their experiences before, during and after the hands-on training. All respondents (n=11) reported that Ocul-AR helped them to learn hands-on microscopy (64% replied that the application helped definitely, 36% that it helped somewhat), as well as helped them to recall microscopy skills (90% definitely, 10% somewhat). Students who used Ocul-AR during the course felt they gained confidence to operate the microscope during the hands-on session (82% definitely, 18% somewhat) and that it lowered their threshold for using the microscope independently (70% definitely, 30% somewhat). Overall, in this article, we show that the Ocul-AR application offers useful solutions to challenges in microscopy teaching and guidance, as well as promotes learning microscopy in a higher education context.

Keywords

Microscopy teaching, mobile app, mobile learning, m-learning, augmented reality

1. Introduction

Microscopy has become an indispensable method for observing living organisms in various research domains, including cell biology and tissue diagnostics. However, obtaining high-quality biomedical image data through a microscope needs expertise, which typically requires hours of practical, in-person training from skilled microscopy professionals. Typically, microscopy training

Proceedings of the Technology-Enhanced Learning in Laboratories workshop (TELL 2023), April 27, 2023, Online.
* These authors contributed equally.
EMAIL: joanna.pylvanainen@abo.fi (A.1); laura.j.mairinoja@utu.fi (A.2); tino.tuomisto@edu.turkuamk.fi (A.3); junel.solis@abo.fi (A.4); diana.toivola@abo.fi (A.5); pasi.kankaanpaa@abo.fi (A.6)
ORCID: 0000-0002-3540-5150 (A. 1); 0000-0003-3552-5416 (A.2); 0000-0003-0972-5262 (A.4); 0000-0001-7165-9839 (A.5); 0000-0002-5890-0883 (A.6)

consists of theoretical and hands-on exercises. The duration of training varies based on the scientist's previous experience and the complexity of the system, ranging from a few hours to up to several days. Previous research has demonstrated that utilizing virtual training methods can reduce hands-on training time by 10-25% [1].

The use of mobile applications has gained popularity in aiding the acquisition of new skills. The pedagogical concept of “mobile learning” or “m-learning” refers to using mobile devices as educational tools. Nowadays it is widely recognized that mobile devices not only facilitate learning in higher education but also play a vital role in informal and lifelong learning [2].

The integration of virtual reality (VR), augmented reality (AR) and educational online resources in higher education have gained popularity as it offers a mixed learning environment, allowing the integration of digital information with the physical environment, creating an interactive learning experience [3]. Various applications implementing VR and AR technology have been created to facilitate teaching and learning in life science and biomedicine. For example, Labster VR (https://www.labster.com/) provides a VR laboratory experience, MyScope is a free online tool that aids in learning about microscope uses [1] and LudusScope is an interactive smartphone microscopy platform that promotes the exploration of microscopic organisms, targeted for primary school children [4]. To our knowledge, there are no AR/VR-based mobile applications for higher education that teach microscopy with a step-by-step approach.

To facilitate the development of researchers' and students' proficiency in using microscopes easily and cost-effectively, we developed a mobile application called Ocul-AR. The main aims of Ocul-AR are to 1) teach students about microscopy, 2) aid during microscope operation, 3) help in troubleshooting unexpected issues, and 4) help refresh skills after extended periods of not using a microscope. The overall goal of the Ocul-AR application is to guide students and researchers into becoming independent microscope users. Here we show that students who used Ocul-AR during a microscopy course gained more confidence to operate the microscope and that Ocul-AR lowered their threshold for using the microscope independently. These outcomes suggest that Ocul-AR has the potential to address obstacles typically associated with teaching and supporting microscopy while enhancing learning microscopy in a higher education context.

2. Development of the Ocul-AR application

2.1 Groups participating in the Ocul-AR application development

During the development and testing of the Ocul-AR application, there were three different active groups:

Development team: Experts on mobile application development, state-of-the-art microscopy, and higher education pedagogics as well as 10 capstone project participants from different disciplines from the Turku University of Applied Sciences (TUAS).

Needs assessment group: 10 students specializing in bioimaging, biomedicine, and cell biology participated in the Needs assessment survey designed to assist the development team in identifying the requirements for the Ocul-AR application.

Pilot testing group: 11 students participating in a basic microscopy course and the pilot study. This group responded to the pilot testing survey during different phases of the pilot study. Members of the Pilot testing group were different from the members of the Needs assessment group.

2.2. Needs assessment for microscopy learning supporting application

The application development started with brainstorming in the multidisciplinary Development team. Concurrently, a Needs assessment survey was sent by email to the students in order to investigate the biggest challenges when trying to use a microscope independently (Table 1), and 10 anonymous replies were received from students who then formed the Needs assessment group. The resulting needs were divided into four thematic groups, and the features of the Ocul-AR application and the project outline were designed based on these themes, complemented by the expertise of the Development team. The project was included in a TUAS capstone course

(https://innovaatioprojektit.turkuamk.fi/en/home-english), where students from different disciplines work in groups with external projects. The capstone group joined the Development team, the visual identity of the application was designed, and the application prototype was created.

Table 1
Needs assessment survey for identifying the requirements for the Ocul-AR application.

QUESTIONS ASKED FROM STUDENTS
Question 1: What is your level of education?
Question 2: What is the name of your program and the university you are studying in?
Question 3: How much hands-on experience do you have in microscopy?
Question 4: What do you think is most difficult in microscopy?
Question 5: What do you think is the most difficult part about using a microscope?
Question 6: What would you like the application to help you with?
Question 7: Would you be interested in using a mobile application based on augmented reality (AR) to help you in learning how to use a microscope?
Question 8: The application will likely include some elements of progress-tracking and user-rewarding. Do you think these would make learning with the application engaging?
Question 9: What would motivate you in learning how to use a microscope using a mobile application?
Question 10: Your idea of a reward system?
Question 11: Do You have any other suggestions or comments regarding this application?

2.3. Results of the Needs assessment survey: Students are interested in using a mobile application for microscopy teaching and support

At the early stages of the Ocul-AR application development, students with none or some hands-on experience with microscopes (Needs assessment group) were asked what they find the most difficult in microscopy, and if they would like to use a mobile application to support their microscopy learning (Table 1). Ten responses were received, and these students indicated encountering challenges in getting started at the microscope (20%), aligning the light path (20%) and other settings (20%) for optimal illumination, and achieving optimal localization and visualization (40%) of the sample (Figure 1). In addition, students reported that they would benefit from an application that would help them align the light path, focus on the sample and fine-adjust the microscope for optimal visualization. All respondents showed interest in using a mobile application for learning microscopy, 70% very much and 30% maybe. Students were interested in a feature that would allow them to track their progress during learning and said that getting rewards would inspire them to continue learning by using the application.

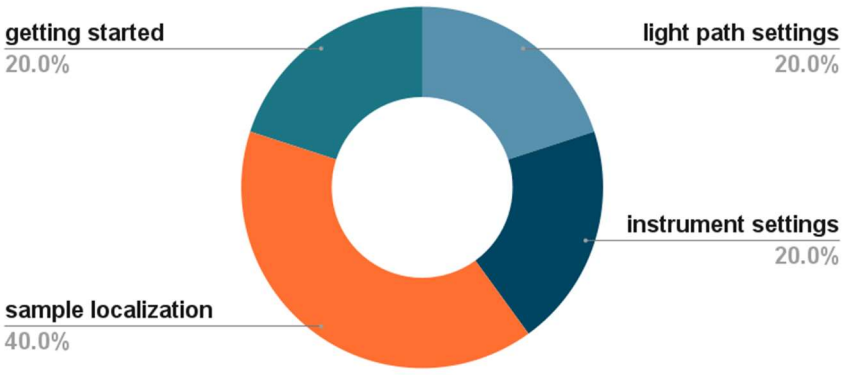

Figure 1: Biggest challenges in using microscopes identified by the Needs assessment group.

2.4. Technical implementation of the application

The Ocul-AR design prototype was created and iterated on in the Figma web-based design software. The source code for the application was written in the Unity 2020.3.3 real-time development platform using the C# programming language, resulting in a mobile application based around a singleton class that manages various application states. These states include an interface, data manager, page manager, quiz feature, and AR feature.

A three-dimensional (3D) model of a Leica DM RXA microscope was created using Blender, a free and open-source 3D creation suite. This model was then used as the basis for implementing a microscope simulation that allows for interaction with different parts of the microscope model, and a simulation of the Köhler illumination alignment process.

The AR feature was implemented using EasyAR Sense 4.4. Quick response (QR) code markers placed on different parts of the microscope allow the user to scan and retrieve information about specific parts.

The application was designed to run on the Android mobile operating system and was distributed to end-user devices via Android Package (APK) files. During the development, incremental updates were distributed to users by updating the APK.

2.5. The Ocul-AR application features and content

The teaching content of the Ocul-AR application was first drafted based on the results of the Needs assessment survey, the experiences of the Development team and planned so that they would support the curriculum of microscopy teaching in Turku. The content is divided into three main hierarchical categories: Level 1 (main menu), Level 2 (submenu), and Level 3 (content), visually represented in Figure 2. At Level 1, there are three categories: *Teach me microscopy*, *Help me at the microscope* and *Help me to troubleshoot* (Figure 2, Figure 3A).

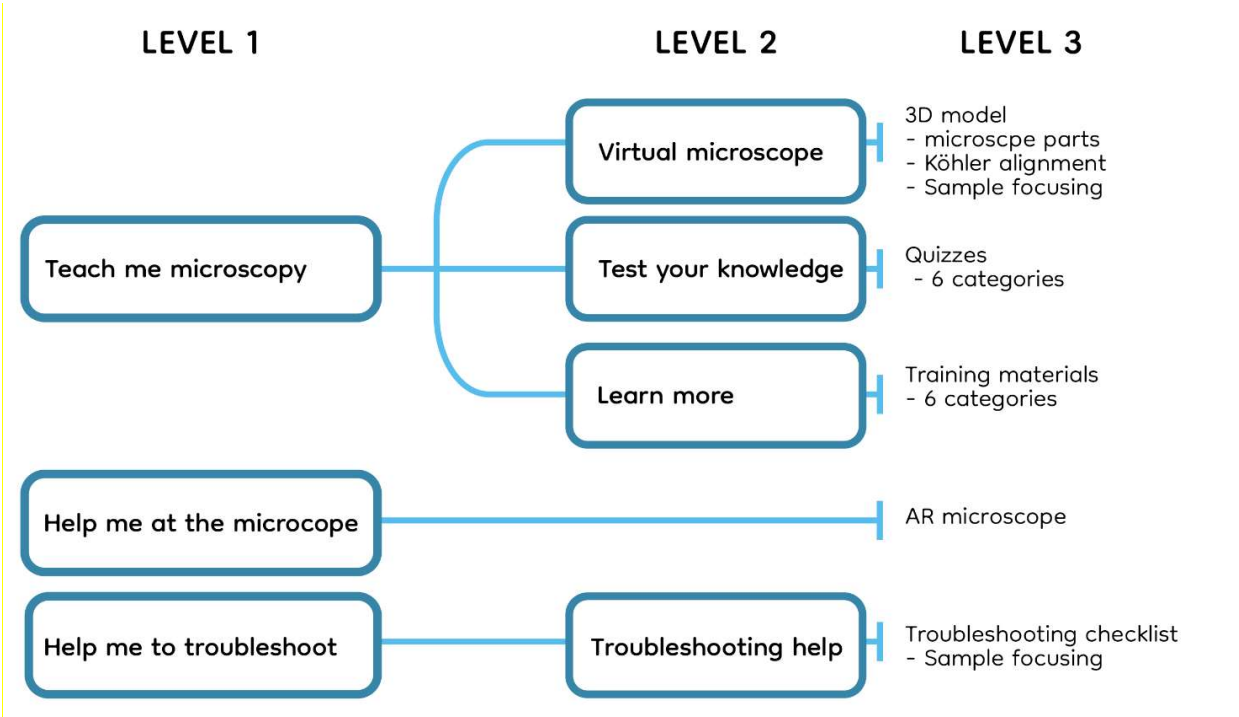

Figure 2: Schematic representation of the Ocul-AR application content. The content is divided into three hierarchical categories: Level 1 (main menu), Level 2 (submenu), and Level 3 (content).

The first level 1 category, *Teach me microscopy,* is intended mainly for independent studies before or during microscopy sessions. This section is further divided into three sections (Level 2); *Virtual microscope*, *Test your knowledge* and *Learn more*. The V*irtual microscope* contains a 3D model of a typical brightfield microscope, the Leica DM RXA microscope (Leica Microsystems), with an interactive tutorial about microscopy parts, how to set optimal Köhler alignment and how to focus on the sample (Figure 3B). This feature can also be used as a step-by-step guide while at this specific microscope. *Test your knowledge* contains a quiz with questions in six different categories: Microscope parts, Köhler illumination, Widefield microscopy, Phase Contrast microscopy, Widefield fluorescence microscopy and Confocal microscopy. The quiz questions can be reviewed at the end of the quiz and the success for each category will be decorated with 1-5 stars (5 being the best), indicating the student's performance. The *Learn more* category consists of training materials from the same six categories above, intended for independent studies or ad hoc help while operating the microscope.

The second level 1 category, *Help me at the microscope,* is intended to be used as support while at the microscope. This feature is currently available for the Leica DM RXA microscope (Leica Microsystems), which is used as a training microscope in our institution. After pressing *Help me at the microscope*, the application opens an AR environment, where it is possible to scan markers or QR codes that have been attached to the microscope beforehand (Figure 3C). These markers guide the student in finding different parts of the microscope and their functions and switching the microscope on and off.

The third level 1 category, *Help me to troubleshoot,* helps the student in case of acute problems. Currently, it offers help in sample focusing by providing a checklist for troubleshooting.

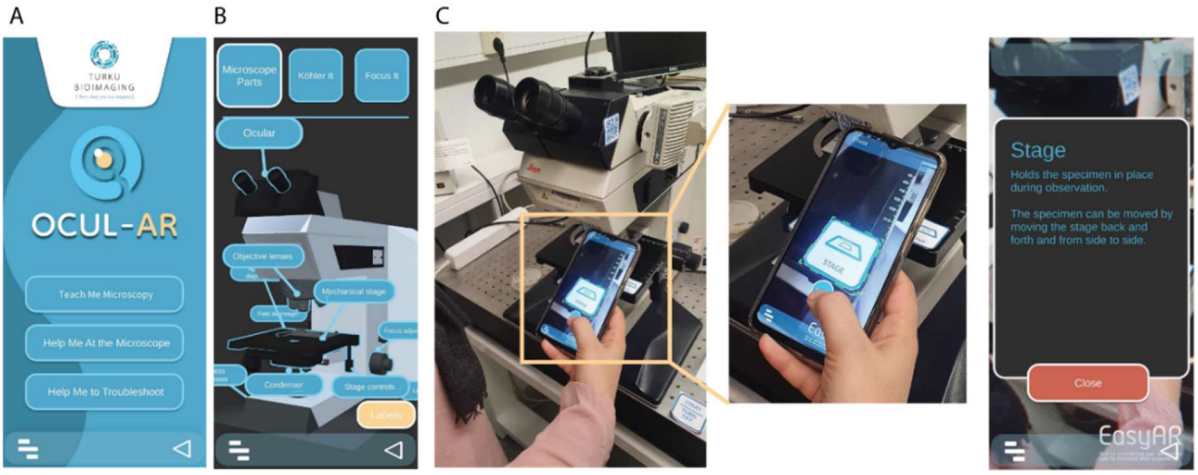

Figure 3: Ocul-AR interface and user experience. A) Ocul-AR main user interface. B) Ocul-AR virtual microscope highlighting microscope parts. C) A student at the microscope using Ocul-AR.

3. Implementing the Ocul-AR application for learning

3.1. The Ocul-AR Pilot study

The application was piloted in a university basic-level microscopy course. The course included an introductory lecture on the parts of the microscope and setting the Köhler illumination alignment, after which information about the Ocul-AR pilot study was delivered to the 45 course participants. Eleven of these volunteered to test the Ocul-AR application as a part of the hands-on microscopy session and responded to the pilot testing survey. Participation in the pilot study and filling out the pilot testing survey was voluntary, and the participating students were rewarded with additional ECTS points. The data collected from the pilot study was used to understand if students benefited from using the Ocul-AR application as support during a basic microscopy course and to facilitate further development of the application. Each volunteer received a personal link to the pilot testing survey and used the same link in every phase of the study. The pilot study consisted of four phases (0-3) and a corresponding set of questions in the pilot testing survey (Figure 4, Table 2).

3.2. Usability of the Ocul-AR application

During phases 1 and 2 of the pilot study, the students were given instructions on how to install Ocul-AR applications and perform designated exercises. Seven participants using an Android operating system on their phones were able to install the application, and 72 % of them were able to install the application directly from the link and follow the phone installation process without needing step-by-step instructions provided by the Ocul-AR Development team. The rest reported that detailed written instructions were helpful for installation. All the participants indicated that the Ocul-AR application was aesthetically pleasing and simple to navigate. The participants noted that the application was appropriate for novice users but suggested that it should include more advanced content if intended for advanced users.

Students also reported how they used the application at the microscope. Without prior knowledge of the microscope, the students were asked to identify microscope parts, perform Köhler illumination, and localize their sample with the help of the Ocul-AR application. To solve these tasks, more than 90% of the students relied on the following three features of the application: *Teach Me Microscopy - Virtual Microscope - Microscopy parts*, *Teach Me Microscopy - Virtual Microscope - Köhler it*, and *Teach Me Microscopy - Virtual Microscope - Focus it*. Additionally, 36% of the students used the *Help me at the microscope* AR microscope feature. Students reported that the step-by-step guide available for the identification of microscope parts, Köhler alignment and focusing were the most helpful features of Ocul-AR.

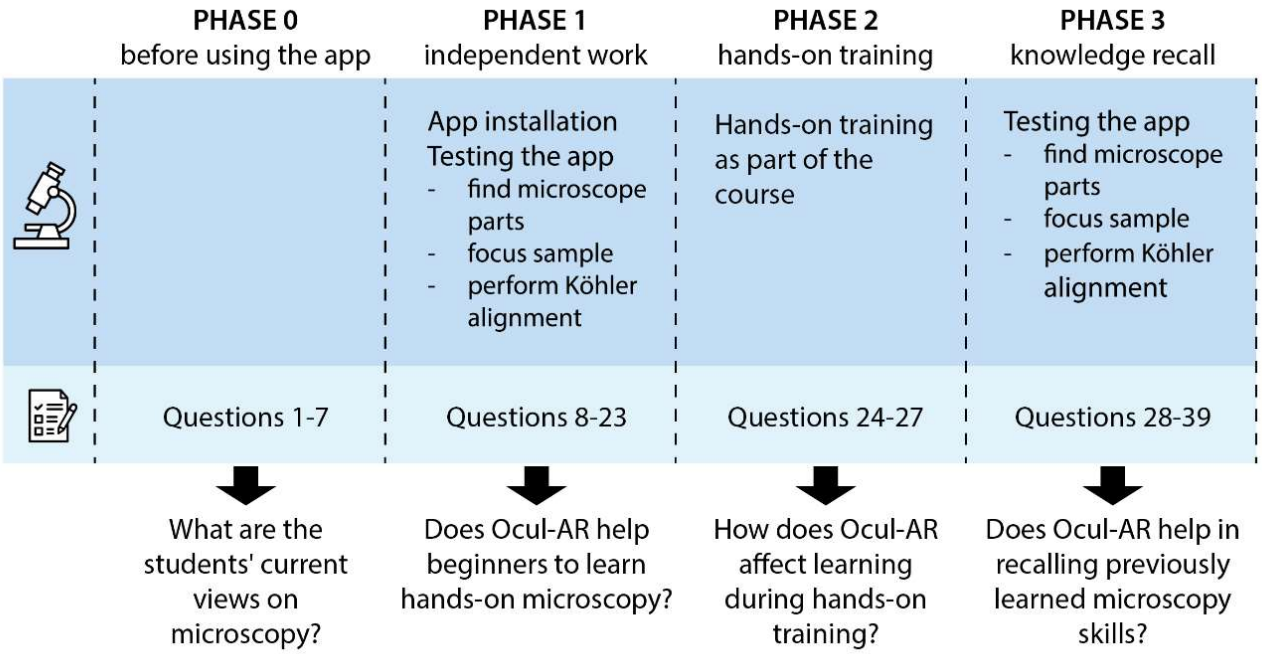

Figure 4: Schematic illustration of the Ocul-AR pilot study.

3.3. Phase 0-1 results: The Ocul-AR application helps students to learn hands-on microscopy

The respondents of the pilot testing survey were novice microscope users, with 64% reporting having no more than 2 hours of prior experience with microscopy. 18% reported having 2-5 hours of experience, while only a small number had more than 10 hours of experience. Respondents reported having participated in short microscopy sessions during their studies, but the majority had not adjusted microscope settings themselves and reported not being independent microscopy users. According to the respondents, when learning microscopy, course materials and lectures were the main sources of

knowledge acquisition (82%), followed by hands-on training (55%) and online videos (45%). Following their initial independent use of the microscope supported by the Ocul-AR application, all participants reported that the application helped facilitate their understanding of microscopy. Specifically, 64% of participants reported that the application was definitely helpful, while 36% reported that it was somewhat helpful. Furthermore, all participants indicated that they would definitely use the application in the future to support their use of microscopes.

Table 2
List of the key questions in different phases of the pilot testing study.

PHASE 0
• How much hands-on experience on microscopy do you have so far? • Describe what kind of hands-on experience you have. • Evaluate your hands-on skills in microscopy • What do you think is the most difficult in learning microscopy? • What materials are you using when learning hands-on microscopy.
PHASE 1
• How much hands-on experience on microscopy do you have so far? • Describe what kind of hands-on experience you have. • How did you use Ocul-AR? • Describe the usability of the app • How was the setup of Ocul-AR? (downloading, opening, etc..). Feel free to comment. • How many times have you opened the Ocul-AR app? • How much time did you spend using the application altogether? • What sections of the application were you using? • What was the most useful content for you? • Did the application help you learn hands-on microscopy? • Please comment on how the application helped you learn hands-on microscopy • At the microscope, three different AR markers were used. Which one did you like the best? • How was the visual appearance of Ocul-AR? • Would you use the application in the future? • How would you improve the app?
PHASE 2
• Did how the application testing help you to follow better the teaching in the hands-on microscopy session? • In general, how useful do you think mobile applications are in teaching/learning? • How did the hands-on microscopy session change your thoughts about the app? What do you think about Ocul-AR now? • In what situations do you think the Ocul-AR application would be helpful? • Do you have any additional comments about the app, the project or this survey?
PHASE 3
• Evaluate your hands-on skills in microscopy • What do you think is the most difficult in learning microscopy? • Have you used light microscopy after the pilot in autumn 2022? • Have you needed Köhler illumination after the pilot in autumn 2022? • Did the application help you to recall hands-on microscopy? • Please comment on how the application helped you to recall hands-on microscopy. • What sections of the application were you using? • What was the most useful content for you? • Has Ocul-AR lowered the threshold for operating the microscope independently? • How comfortable do you feel using the microscope independently?

3.4. Phase 2 results: Self-study with Ocul-AR application by the microscope helps students to follow the conventional microscopy hands-on training

Following the initial independent session at the microscope during pilot study phase 1, the students participated in a teacher-guided hands-on session that was a mandatory part of the course that provided the framework for the pilot study. The pilot testing survey results showed that 82% of the respondents who had used Ocul-AR before the hands-on microscopy session reported that the application was helping them to follow the teaching during the session. 18% reported that following was somewhat easier. None of the participants thought that the application would have interfered with the guided hands-on training. Instead, the student that tested the application during training reported that the application made them more comfortable around microscopes and helped them to follow the hands-on session.

3.5. Phase 3 results: The Ocul-AR application supports students in becoming independent microscopy users

Pilot study phase 3 was conducted to evaluate the long-term effectiveness of Ocul-AR in learning microscopy. During this phase, students were requested to perform the same tasks as in phase 1, but after a gap of three months following the guided hands-on session of the course. In both phases, the students spent were given one hour on the microscope. To solve the given tasks, in phase 1 the respondents reported using mostly the *Virtual microscopy* section with three topics (*Microscopy parts, Köhler it, Focus it*). The same three topics were popular also in phase 3. However, the use of self-study material where the emphasis was on knowledge recall (*Test Your Knowledge, Learn more sections, Help me at the microscope)* increased in phase 3. The usage of *Help me at the microscope* increased from 11% to 21% from phase 1 to phase 3 (Figure 5A).

When asked how the Ocul-AR application impacted the students' confidence in using a microscope, 90% reported that the application helped them to recall hands-on microscopy, while 10% reported a slight improvement. Most participants reported having forgotten how to perform Köhler alignment or how to focus on the sample after the guided hands-on session. As the application was used for these specific tasks during teaching, the students reported that it was a familiar resource for revising how to perform these tasks. 64 % of the students felt that the Ocul-AR application definitely helped them in becoming independent microscopy users, whereas 27 % reported that the application helped somewhat. 9 % of the students felt that Ocul-AR did not significantly help them in becoming independent microscopy users (Figure 5B).

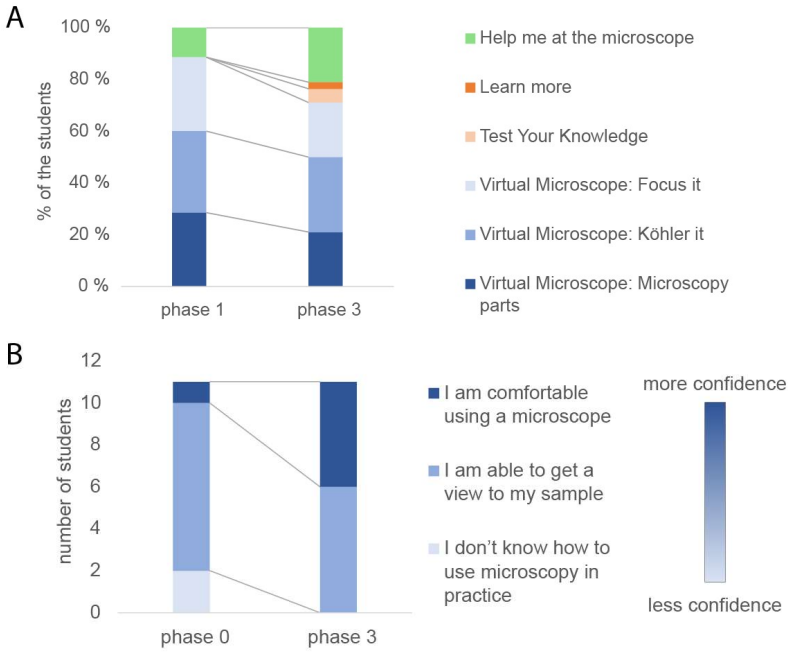

Figure 5. Ocul-AR application in knowledge recall.

4. Discussion

The journey of becoming an independent microscopy user typically begins during master's degree level studies. To be able to efficiently implement microscopy in the later stages of a career, it is crucial to develop a solid foundation in imaging techniques. However, since everyone's career path and learning are unique, proficiency in microscopy may develop earlier or later during one's career. It is important to make microscopy training and knowledge easily accessible to everyone, at any time. To support microscopy learning, we created the Ocul-AR application, which aims to teach students about microscopy, support students while using the microscope and help in refreshing skills after a break in microscope usage. The effect of Ocul-AR on learning was studied in conjunction with a university-level theory and hands-on microscopy course. We show in this pilot study that students who used the Ocul-AR application during the course experienced that they gained more confidence to operate the microscope during the course and it supported them in becoming independent microscopy users afterwards.

Mobile learning can take a formal or informal learning approach [5]. While a traditional classroom setting (formal learning) is fundamental in facilitating learning, it is equally important for students to have access to dependable study resources in a format that suits their preferred learning environment. Further, students and teachers operate in complex and constantly evolving learning environments, which they adapt to based on different needs, preferences, and abilities [6] and therefore innovative teaching and learning approaches are necessary to empower students to enhance their learning experience and reach their academic objectives more efficiently [7]. Ocul-AR's interactivity is crucial when adapting it for higher educational purposes. As a result of the VR and AR features, students could engage with the microscope and access microscope-specific information from their homes or while physically using the equipment. By combining mobile learning in the classroom with practical training, a broader range of learners could be accommodated. Furthermore, some students with learning difficulties can benefit from utilizing diverse types of learning materials. While practical hands-on training cannot be entirely replaced, our solution can supplement it by providing additional support.

Most students who participated in the pilot testing study were beginners in hands-on microscopy. The abundance of knobs and controls on microscopes can be intimidating and overwhelming for a first-time user. The objective of this project was to assist students in becoming independent microscopy users by incorporating the Ocul-AR application into hands-on training. Our results suggest that training students using the Ocul-AR application improved their confidence in operating microscopes independently and that the feeling of being lost was avoided. One respondent described their experience with the following words: *"It [Ocul-AR] helped me identify the parts correctly and easily. I liked that the virtual microscope was modelled after the real one. I think the app with the visual aid was a lot more helpful in setting the focus and Köhler illumination than a set of written instructions could have been. It also made me more confident that I was for sure tweaking the right parts."*

The Ocul-AR application provides an easy and accessible tool to support microscope learning and teaching, as well as refreshing skills. However, the Ocul-AR application still has several limitations. The current version of Ocul-AR supports only one type of microscope. However, we aim to expand its compatibility to include more microscopes and microscopy techniques in the future. Furthermore, the application does not currently provide teachers with the ability to modify or add new content. This feature is slated for inclusion in the next version of the Ocul-AR application, making it more customizable for each imaging facility, and useful to a broader community. In addition, other prospects include the implementation of gamification to the Ocul-AR application to increase the motivation to learn more about microscopy independently. Overall, the Ocul-AR application has the potential to provide helpful solutions to typical challenges in microscopy teaching and support, as well as promote learning microscopy in a higher education context.

5. Application availability

The Ocul-AR application with user instructions and scan markers for AR are all available on the Turku Bioimaging website: www.bioimaging.fi/ocul-ar.

The source code for the Ocul-AR mobile application is currently not available for general distribution pending plans for further technical development. In some cases, the source code may be

shared subject to the discretion of Turku BioImaging. Please contact the corresponding author for more information.

6. Acknowledgments

JWP was supported by the Health Campus 2.0 project (Academy of Finland), LM was supported by the Drug Research Doctoral programme in the University of Turku, and AIIS and ENVISION_2027 Erasmus+ projects, TT was supported by BlueSkies funding (University of Turku), JS was supported by the Pix4Business project (European Regional Development Fund).

We would like to acknowledge the Turku BioImaging team, including Solveig Eriksson, Dado Tokic, Rafael Díaz and Marcela Rivera for helping with brainstorming and design. Special thanks go to the team of capstone students from Turku University of Applied Sciences for laying the groundwork for this project; Roulin Laine, Pavel Smagljuk, Emil Mustonen, Waltter Kettunen, Milla Suomalainen, Suvi Karvanen, Tino Tuomisto, Viivi Virtanen, Aileen Van Dewetering and Aku Lavonen, and senior lecturer Taisto Suominen, who was leading the capstone group. In addition, we want to thank all the students who volunteered to test the app. We would also like to thank the imaging facility at Biosciences, Åbo Akademi University and the Cell Imaging and Cytometry Core, Turku Bioscience Centre, Turku, Finland, for their technical microscopy support, enabled by Biocenter Finland and Euro-BioImaging Finland.

7. References

[1] B. Cribb, J. Shapter, and M. Apperley, "Online Education and Training for Microscopy and Microanalysis: MyScopeTM," *Microsc. Today*, vol. 24, no. 4, pp. 44–49, Jul. 2016, doi: 10.1017/S1551929516000353.

[2] S. Sophonhiranrak, "Features, barriers, and influencing factors of mobile learning in higher education: A systematic review," *Heliyon*, vol. 7, no. 4, p. e06696, Apr. 2021, doi: 10.1016/j.heliyon.2021.e06696.

[3] B. Somerkoski, D. Oliva, K. Tarkkanen, and M. Luimula, "Digital Learning Environments - Constructing Augmented and Virtual Reality in Fire Safety," in *Proceedings of the 2020 11th International Conference on E-Education, E-Business, E-Management, and E-Learning*, New York, NY, USA, toukokuu 2020, pp. 103–108. doi: 10.1145/3377571.3377615.

[4] H. Kim *et al.*, "LudusScope: Accessible Interactive Smartphone Microscopy for Life-Science Education," *PLoS ONE*, vol. 11, no. 10, p. e0162602, Oct. 2016, doi: 10.1371/journal.pone.0162602.

[5] S. Kumar Basak, M. Wotto, and P. Bélanger, "E-learning, M-learning and D-learning: Conceptual definition and comparative analysis," *E-Learn. Digit. Media*, vol. 15, no. 4, pp. 191–216, Jul. 2018, doi: 10.1177/2042753018785180.

[6] K. Carraro and R. Trinder, "Technology in formal and informal learning environments: Student perspectives," *Glob. J. Foreign Lang. Teach.*, vol. 11, no. 1, Art. no. 1, Feb. 2021, doi: 10.18844/gjflt.v11i1.5219.

[7] A. A. Sewagegn, B. M. Diale, A. A. Sewagegn, and B. M. Diale, *Empowering Learners Using Active Learning in Higher Education Institutions*. IntechOpen, 2019. doi: 10.5772/intechopen.80838.