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REMOTE LEARNING IN VIRTUAL BIOLOGY EDUCATION: SCIENCE PROCESS SKILLS ACQUISITION IN MICROSCOPY

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Abstract

Teaching and learning in the 21st century have increasingly been transformed to accommodate remote learners who are not limited by time and geographic location. In biology education, one of the challenges of remote learning is the acquisition of science process skills that are related to the subject. This research reports on the use of virtual laboratories in complementing students' microscopy skills through an inquiry-based learning approach. 98 first-year students were conveniently sampled to participate in the research following an embedded mixed-method approach. For the quantitative aspect of the study, a quasi-experimental design in which no control groups were used was employed. A pre- and post-test of students' science process skills acquisition in microscopy was conducted, followed by a desktop analysis of students' perceptions of their virtual microscopy learning experiences captured on discussion boards. The results from the analysis of test scores showed no significant differences in students' content knowledge of the subject. However, the paired sample T-test revealed a significant positive shift in the mean science process skill scores obtained post-intervention. Content analysis of recorded experiences on Blackboard discussion boards indicated three main themes, which showed that virtual laboratories played a significant role in extending remote science learning. Based on these findings, it was concluded that while virtual laboratories may not significantly affect biology content knowledge acquisition in the short term, they clearly enhance the development of certain basic and integrated science process skills among remote students. These findings underscore the potential of virtual tools to bridge the practical skill gap often associated with online science education. A key challenge that students highlighted was the difficulty in replicating the hands-on experience of traditional microscopy, prompting the need for innovative virtual designs that are closer to real experiences. Based on the findings, virtual laboratory learning is recommended for remote learning settings where a level of skill mastery is required. Future studies could employ control groups in order to establish stronger causal relationships. The implications of the study are linked to the value that virtual laboratories can add to remote biology education by potentially increasing students' access to learning opportunities regardless of their physical location and time.

Keywords: *Remote learning, science process skills, virtual laboratories, virtual microscopy (VM).*

1. Introduction and background to the study

One of the key laboratory tools in modern biology laboratories is the Microscope, which enables students to participate in inquiry in biology and related fields. Microscopy, defined as the scientific technique of using microscopes to observe and analyse specimens that are too small to be seen with the naked eye, allows students to magnify and resolve the fine details of biological specimens at both the cellular and molecular levels (Murphy & Davidson, 2012). With the use of a microscope, students can examine the properties, composition or even behaviour of different specimens, in turn building their science process skills for inquiry-based learning in biology. There are different types of microscopes that serve this purpose, including optical, electron, light (simple and compound) and the subfields of microscopy covered by these broad domains (Herodotou et al., 2025).

Traditional microscopy, while effective, presents challenges such as high costs, maintenance, and limited access to equipment in resource-constrained settings (Whalley et al., 2020). On the other hand, Virtual microscopy (VM), which uses digital slides viewed through a computer interface, has become a worthy complementary tool in science education. VM allows students to interact with high-resolution images of specimens, annotate observations, and collaborate remotely, potentially enhancing science process skills, accessibility to microscopy and unlimited engagement (Dee, 2009; Dickerson & Kubasko, 2007).

Science process skills (SPS), as defined by Padilla (1990), encompass the basic and integrated skills that scientists use to explore natural phenomena. These skills are crucial for transforming abstract scientific concepts into a clear, concrete understanding, particularly during scientific investigations. By mastering SPS, students can better grasp the principles of science (in this case, biology) through active participation in investigations that involve observation, experimentation, and inference. However, the development of SPS, particularly in biology, is often hindered by the limited availability of resources necessary for traditional laboratory-based experiences. VM offers a platform to bridge this gap by simulating real-world biology investigations, enabling students to practice SPS in a controlled, repeatable environment (Maity et al., 2023). Despite its potential, the effectiveness of VM in cultivating SPS remains underexplored, particularly in diverse educational contexts.

This study, therefore, investigates how virtual laboratories can be used in complementing traditional microscopy skills through an inquiry-based approach, with the main goal of developing their SPS. The study also addresses gaps in the literature regarding the pedagogical affordances of VM, its impact on student learning outcomes (in this case, the acquisition of SPS). The findings from this study could explicate approaches that can be employed for teaching microscopy in remote settings.

1.1. Research gaps

Since the 2020 pandemic, the need for educators to future-proof teaching has become increasingly important. Virtual microscopy (VM) is one way in which educators could enable remote learning as a complementary strategy when access to traditional laboratory facilities is limited. However, while VM has been praised for increasing access to microscopy (Maity et al., 2023), few studies have systematically evaluated its role in developing SPS. Existing research, like Paxinou et al. (2022), often focuses on cognitive and procedural skills associated with VM, but little attention is given to the SPS that could be attained in the requisite procedures. Furthermore, there is limited evidence on how VM performs across different educational contexts outside of the medical field and where access to technology and prior exposure to inquiry-based learning may vary. This study seeks to address these gaps by addressing the following objectives:

- To examine the extent to which VM enhances SPS,
- To evaluate the perspectives of students on their use of VM in remote settings and
- To report on the optimal instructional strategies for integrating VM into science curricula.

2. Literature review

Literature underscores the potential of VM to transform science education. In the study by Dee (2009), the researcher posited that VM enables students to explore digital slides at their own pace, fostering self-directed learning and critical observation skills. The systematic review by Maity et al. (2023) has several researchers reporting that VM improves access to rare or fragile specimens, democratizing microscopy education. However, challenges include the need for educators to be adequately trained and for all students to have the relevant devices and connectivity to tap into VM's benefits (Penn & Ramnarain, 2019).

Regarding SPS, Bybee (2011) emphasises that skills like hypothesising and data analysis are best developed through active engagement in authentic scientific tasks. VM supports such tasks by allowing students to manipulate variables (e.g., magnification) and record observations systematically (Herodotou et al., 2020). More research in the domain of remote and virtual learning suggests that virtual tools become pedagogically effective when they are used in complement with traditional tools using inquiry-based learning approaches (Braun & Kearns, 2008; Penn & Mavuru, 2020). Mixed-methods approaches, combining VM with traditional microscopy and inquiry-based learning, have shown promise in enhancing SPS but require further exploration.

2.1. Theoretical lens

Theoretically speaking, the study is guided by a multi-theoretical framework which combines Mayer's theory of multimedia learning (Mayer, 2009) and the active learning theory as suggested by Bonwell and Eison (1991). Multimedia learning optimises information delivery, ensuring cognitive load is managed through the thoughtful use of words, sound and images. On the other hand, active learning shifts learners from passive recipients to engaged participants through interactive tasks, problem-solving, and critical reflection. This combination of hands-on interactivity and multiple representations enhances virtual learning environments: multimedia presents content clearly, while active strategies ensure deeper processing and knowledge construction. The result of the merger is a dynamic virtual experience that truly empowers learners to develop a comprehensive understanding and lasting skill acquisition.

The literature also highlights contextual factors that tend to affect science learners. In resource-limited settings, VM can reduce costs associated with physical microscopes and laboratories, but digital literacy and access to reliable internet remain barriers that should be addressed (Herodotou et al., 2020). Moreover, cultural attitudes toward technology-mediated learning influence student engagement to a great extent and should always be considered.

3. Methodology

This study employed an embedded mixed-methods research design to investigate VM's impact on SPS acquisition. A quasi-experimental approach was preferred as it catered for the shortcomings of ethical issues that are related to controlled experiments in social science settings. 98 first-year undergraduate students (72 females and 26 males) in an intermediate phase teacher education programme were purposively selected to participate in a pre-science process skills test adapted from the intervention and the post-test. An integrated SPS pre- and post-tests, adapted from Mokhaba (2009), were piloted with a non-participating group of students and then administered. The SPS test measures skills such as *observation, hypothesis formulation, classification, stating operational definitions, Graphing and interpretation, experimentation and data analysis*. Scores of pre- and post-tests were analysed using paired t-tests to determine significant differences before and after the intervention with VM. The intervention carried out utilised the freely available "virtual microscope" (https://www.ncbionetwork.org/educational-resources/elearning/virtual-microscope) developed by ncbionetwork on an open license to use by educators and students.

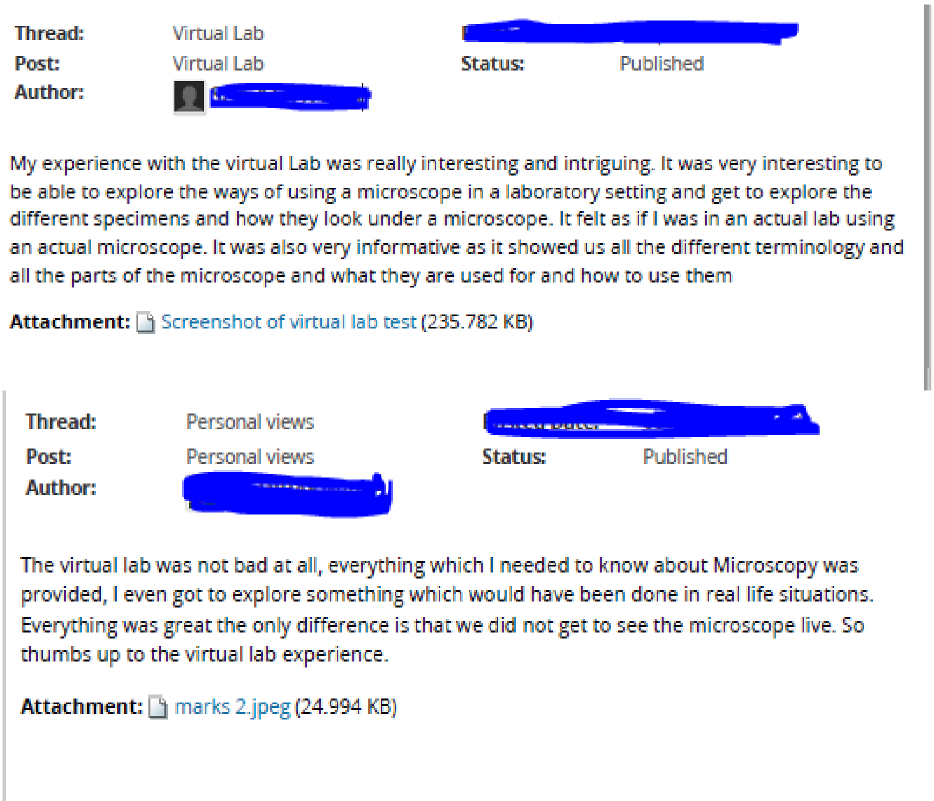
Follow-up qualitative thematic content analysis of the discussion forum feed of all participants was conducted to establish perspectives of students on VM's usability in remote settings, engagement, and alignment with SPS. During the intervention, an inquiry-based approach to learning was employed, where participants needed to compare virtually observed biological specimens and the actual specimens. Observations of use and interviews were also conducted but are not reported within the scope of this proceeding. Thematic analysis, guided by Braun and Clarke's (2006) framework, identifies recurring patterns in the qualitative data. The mixed-methods approach triangulates findings, ensuring a comprehensive understanding of VM's effectiveness.

4. Findings

Quantitative results indicate that the VM group showed significant improvement in SPS scores ($p < 0.05$), between pre- and post-SPS tests, particularly in observation, classification, operationally defining and data analysis components of the test. However, no significant differences were found in graphing, hypothesising and experimenting skills, suggesting that VM may require additional scaffolding to support higher-order thinking. A paired samples t-test was conducted to evaluate the effectiveness of the virtual microscopy intervention on students' science process skills. The results revealed a statistically significant increase in post-test scores ($M = 18.35$, $SD = 2.78$) compared to pre-test scores ($M = 15.32$, $SD = 2.73$), $t\ (97) = 18.58$, $p < .001$. This finding suggests that the intervention had a meaningful and positive impact on students' performance in certain aspects of the science process skills test.

Qualitative findings, as captured on discussion boards, revealed three key themes that suggested the following: 1. that students valued the interactive features in the virtual microscopy lab, such as adjusting the optical lenses, handling equipment, adding oil and annotation tools, which enhanced their engagement and precision when observing specimens. 2. The remote affordance of VM granted the freedom to revisit difficult aspects over and over again, even in the comfort of students' homes, and lastly, 3. Students agreed that VM was an important prerequisite for preparing for traditional instruction. The lab assistants also noted that the use of the discussion board forum for sharing experiences was a worthy tool in facilitating collaborative learning remotely, as students could share screenshots of their experiences in real time. Figure 1 below shows a sample of discussion board images.

Figure 1. Sample discussion board threads.


Thread: Virtual Lab [redacted]
Post: Virtual Lab **Status:** Published
Author: [redacted]

My experience with the virtual Lab was really interesting and intriguing. It was very interesting to be able to explore the ways of using a microscope in a laboratory setting and get to explore the different specimens and how they look under a microscope. It felt as if I was in an actual lab using an actual microscope. It was also very informative as it showed us all the different terminology and all the parts of the microscope and what they are used for and how to use them

Attachment: Screenshot of virtual lab test (235.782 KB)

Thread: Personal views [redacted]
Post: Personal views **Status:** Published
Author: [redacted]

The virtual lab was not bad at all, everything which I needed to know about Microscopy was provided, I even got to explore something which would have been done in real life situations. Everything was great the only difference is that we did not get to see the microscope live. So thumbs up to the virtual lab experience.

Attachment: marks 2.jpeg (24.994 KB)

Figure 1 shows some excerpts of students' discussion board feeds as extracted from Blackboard. All permissions and ethics dimensions were followed. A key challenge identified by students was the need for hands-on experience to be added to the virtual aspect. Other challenges that were easy to resolve included a few technical glitches and connectivity issues.

5. Discussion

The findings align with Dee's (2009) assertion that VM promotes self-paced and autonomous learning, as participant students demonstrated stronger observation and analysis skills after engaging on their own with the virtual microscope. Profound gains like trial and error, unlimited access and the levels of interactivity with the virtual tool concur with the findings of other studies (Herodotou et al., 2020; 2025; Maity et al., 2023). Some of the challenges, like the lack of authentic experiences, echo Penn and Mavuru's (2020) observation that technology must be paired with explicit pedagogical strategies and traditional experiences for maximum benefit. Mixed-methods instruction, combining VM with inquiry-based activities, appears to maximise the learning outcomes in this particular intervention study.

It was also worth noting from the findings that virtual tools will always need to be complemented with actual traditional experiences, especially when it comes to the acquisition of science process skills. Contextual factors, such as the availability of digital tools and strong internet, significantly influence VM's effectiveness and may affect scalability in resource-constrained settings, corroborating Maity et al. (2023). The study highlights the need for teacher training to integrate VM effectively into remote and blended education settings as part of equipping students with innovative ways of learning in the digital age.

6. Recommendations and conclusions

Virtual microscopy holds a significant promise for enhancing science process skills, offering an accessible and engaging platform for scientific inquiry. This study demonstrates that VM improves observation, classification, operational definition, and data analysis skills significantly, though its impact on hypothesising requires further pedagogical support. By addressing contextual barriers and integrating VM into mixed-methods instruction, educators can maximise its potential for students' learning. These findings contribute to the growing body of evidence on technology-enhanced science education, offering actionable insights for practitioners and policymakers. Based on the findings, virtual laboratory learning with VM is recommended for remote learning settings where a certain level of skill mastery is required. Future studies could employ control groups in order to establish stronger causal relationships, as this was the main limitation of this study. The implications of the study are linked to the value that virtual laboratories can add to remote biology education by potentially increasing students' access to learning opportunities regardless of their physical location and time.

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