

Virtual Microscopes and online learning: Exploring the perceptions of 12 teachers about pedagogy

Abstract

This paper examines the pedagogical integration of Virtual Microscopes (VMs) in Virtual Learning Environments (VLEs), to identify best practice and improve online pedagogy. It has captured the perspectives of 12 Health and Earth Science university teachers, through in-depth interviews, about the current integration of the VM in online teaching, benefits and challenges, and their recommendations for enhancing online and distance learning. Findings revealed that the VM has been integrated in online courses in varied ways, addressing diverse learning objectives. Teachers noted two particular challenges: a) the need for support throughout the lifecycle of a course, and while students are using the VM, that will complement the introductory support currently provided, and (b) the design of VM learning activities that promote higher order thinking skills. Implications about the significance of engaging teachers with the process of designing online courses and using the VM to enable remote learning in cases of emergency are discussed.

Keywords: online learning; virtual microscopes; teachers; higher education

1. Introduction

Virtual Learning Environments (VLEs) such as Moodle and Blackboard, are digital environments commonly used in higher education to host lectures, tutorials and practical materials for online and distance courses (e.g., Barajas & Owen, 2000). Although they are a flexible way of delivering teaching and learning, VLEs face significant challenges including student engagement and retention (Bawa, 2016), infrastructure problems (Fry et al., 2015) and appropriate design to enhance feedback and assessment (Allan & Bentley, 2012). In terms of the latter, there is an increasing interest by educational stakeholders to test and document the effectiveness of different types of pedagogy on student learning in order to help teachers make informed and evidence-based teaching decisions (Herodotou et al., 2019). In online and distance learning, evidence-based quality standards about how to design online learning experiences that have a positive impact on students' learning and engagement remain scarce. There is a lack of clear understanding of how the varied design features of VLEs such as videos, simulations, and lectures are embraced by students and relate to

specific learning outcomes such as higher grades, assignment submission, enhanced interactions and communication (e.g., Jaggars & Xu, 2016; Kintu et al., 2017).

In this paper, we examined the perceptions of 12 teachers from a distance learning higher education institution about how VMs are integrated into teaching and whether they are perceived to support students' learning and engagement. In particular, we focused on the following dimensions: a) how the VM is currently used in teaching, b) perceived benefits and challenges, and c) teachers' recommendations about how best to integrate VMs in teaching. We perceive teachers as a significant source of information for evaluating and improving online pedagogy, that is teaching, learning and assessment in online settings. Teachers interact with both students and the course material and are thus best placed to identify what works and what does not work for students. Traditionally, teachers have been perceived as those executing a predefined curriculum; yet a significant line of work is currently viewing them as 'designers or design researchers', shifting the focus of the teachers' role from implementing 'set' curricula to experts in the science of teaching (Persico et al., 2018). Teachers as designers hold the potential to initiate sustainable and large-scale improvements in teaching and learning in higher education (Bennett & Agostinho, 2018). In light of this change, we adopted a participatory approach to the evaluation of the VM that sought to capture teachers' perspectives and we used this knowledge to inform and improve the design of online courses.

2. Literature Review

Studies have showcased the importance of specific design features in supporting online learning including: a) online interpersonal interaction between students and instructors (Jaggars & Xu, 2016), b) active discussions amongst students (Swan, 2001), c) embedded questions in the design of interactive videos (Vural, 2013), d) formative assessment to provide ongoing feedback during learning (Lawton et al., 2012), e) social network sites to improve online communications (Brady et al., 2010), f) experiential simulations integrated in online courses (Beckem, 2012), g) citizen science tools to promote inquiry learning (Waldrop, 2013; Herodotou, Sharples et al., 2018), h) virtual science labs being equally as good as hands-on physical labs (Darrah et al., 2014), and i) teacher-facing analytics predicting students at risk of failing (Herodotou et al., 2020).

Virtual laboratories enable students to conduct experiments at their own time and pace, using simulations, and they have been shown to enhance learning and understanding in areas such as Physics and Chemistry (Wolski & Jagodziński, 2019; Wästberg et al., 2019). One of

the tools of a virtual laboratory which has not yet been adequately examined is the Virtual Microscope (VM). VM is a web-based tool integrated into VLEs to enable simultaneous online access to images (samples) that can be manipulated by multiple students (e.g., zoomed and panned). VMs are used in Biology and Health Sciences (Becerra et al., 2015), and Earth and Materials Sciences (Tetley & Daczko, 2014). At The Open University - the university under study, a first version of a web-based VM was created in 2010, replacing a CD-based one, with positive initial reactions from students (Whalley et al., 2011). Overall, students and teachers are satisfied and enthusiastic when VMs are used in teaching (Brown et al., 2016) and their performance is equally as good as using physical microscopes. Yet, the best learning outcomes are shown to result from combining virtual and physical microscopy (Becerra et al., 2015). It is noted, though, that during the last few years the design of the VM has been further refined and elaborated and this may have an impact on the learning outcomes potentially gained through its use. This suggests that additional examinations are needed to validate reported outcomes from combining virtual and physical microscopy.

Few studies have examined the pedagogical integration of the VM in the learning design of online and distance learning courses and identified best practice around its use. Childers and Jones (2015) examined students' perceptions about 'real remote investigations', in particular the impact of ownership and virtual presence when using a scanning electron microscope. Through a Randomized Control Trial, they identified that the experimental group that was given choice over which insect to study was less distracted during the remote investigation than the control group. In contrast, the control group reported easier use of technology than the experimental group. Students described the investigation as being 'very real', yet the teaching staff was less likely to describe it as such. In a follow-up publication, Childers and Jones (2017) identified three factors influencing the students' experience during a remote investigation: (a) science learning drive, that is, students' perceptions of science competency and motivation to do science, (b) environmental presence, that is, perceptions of control over remote technology and relatedness to scientists, and (c) inner realism presence, that is, students' perceptions of how real the remote programme is and recognizing themselves as being science-oriented.

Through a mixed-methods study, Herodotou, Muirhead et al. (2018) examined students' usage and perceptions of online microscopy, in online and blended learning conditions. In blended learning conditions, students had access to both a virtual and a physical microscope. No differences in perceived learning gains between online and blended students were found. Yet, students in blended settings perceived the integration of the VM in their courses as being

more enjoyable than online students. In blended settings, the VM formed part of varied activities such as quizzes, assessment, and homework and it was complementary to the use of a physical microscope. In contrast, in online settings it was the basic means for observing and identifying sections on slides. Online students stressed the need for additional support from their tutors that would provide feedback to their understanding of what VM slides show. The study concluded that blended learning conditions better support students' engagement and learning with the VM due to the 'full integration' of the VM in the courses under study.

3. Aim and Research Questions

The aim of this paper is to identify benefits and challenges in the current integration of VMs in online teaching and provide recommendations about how online instruction with VMs could be enhanced. Twelve (N=12) in-depth interviews with teachers involved in the design, presentation and facilitation of online courses that embed VMs in their structure provided insights about the following Research Questions (RQs):

RQ1: What are the teachers' perceptions about the current integration of the VM in online and distance science courses?

RQ2: What are the teachers' perceptions about the benefits and challenges from using the VM in online and distance science courses?

RQ3: What are the teachers' recommendations for improving the design of online and distance science courses that make use of the VM?

In the next section, we present how the VM is currently embedded into the design of online and distance courses under study. We then present the methodological design of this study, the process of data analysis, discussion of findings and conclusions.

4. The Virtual Microscope in Online Courses

Two versions of the VM (Virtual Microscope) are considered: (a) The first is the VM for the Earth Sciences used in the online courses under study (see Figure 1). This is a web-based microscope that students can access through their browsers. It is an open educational resource that was originally designed to provide access to igneous, sedimentary and metamorphic rocks and broaden participation in the teaching of Earth Sciences (see <https://bit.ly/3ocdfP6>). (b) The second VM is for Histology and Pathology and is available on the OpenScience Laboratory website as an open educational resource using slides compiled from a range of institutions (see Figure 2). This is also a web-based microscope that students can access through their browsers (see <https://bit.ly/3n4R7qT>)

[Insert Figures 1 and 2 here]

The VMs are integrated into Earth Science and Biology courses via hyperlinks in the online text (see Figures 3 and 4). Typically, students are introduced to virtual microscopy during the first few weeks of a course. They are asked to complete activities that make use of the VM. These activities ask students to visit the VM website, read the instructions about how to use the VM, read the notes and calibration and photography files and work through the slides by reading the descriptions of each one. Students are also advised to quote the coordinates of any features of interest for discussion with their teacher and peers. Activities may be followed by specific questions such as “Examine Slides 1–3 (nematode) 6, 7, 13, 16 (flukes) and 17 (tapeworm) in the ‘Parasites II’ set. Describe how each group of parasites obtains nutrients and removes waste”. A “Reveal answer” button allows students to access the correct answer (see Figure 4). Figures 3 and 4 are screenshots of activities in an undergraduate Year 3 Health course.

[Insert Figures 3 and 4 here]

In a different course - Year 1 Science: Concepts and practice - students are asked to identify the texture of rock samples and draw conclusions based on their observations (see Figure 5). They can preview and manipulate three different views of specimens: the whole specimen, a zoomable image and the microscope view. They can select the texture and classification from a multiple choice menu and check whether their responses are correct by pressing the check button (see Figure 6).

[Insert Figures 5 and 6 here]

5. Methodology

a. Context of the study

Online courses at The Open University UK (OUUK) are designed and delivered collaboratively by dedicated teams focused on technology-enhanced learning, development and production, and facilitation, monitoring and student support. These teams are interdisciplinary in nature and consist of academics, academic-related, secretarial staff, specialist and external consultants when appropriate. Amongst the course production

activities are the creation of course material (print, video, other media), the Virtual Learning Environment (VLE) hosting the course, the processing of rights applications, advice on the pedagogy (learning, teaching, assessment), technology and learning design with an emphasis on accessibility, and external assessment of the course during production by experts in the areas of knowledge and practice of the course. During the course presentation (the period when students are studying the course), activities include quality enhancement (that is monitoring and alignment of tutors' assessment with the university standards), monitoring of student learning experience and performance, responding to plagiarism processes, assessment of student performance and award of grades to students, asynchronous forum support and synchronous tutorials with students. It is noted that student tutorials are optional and student attendance levels may vary. Participants in this study had varied roles either in course production or course presentation (see next section).

b. Sample

Twelve academics (N=12; male=7, female=5) (see specific roles in Table 1), identified through a snowballing sampling technique expressed interest in taking part in the study. They were selected based on the criterion that they had previous experience of using the VM in online and distance learning courses. Four (n=4) of the participants used the VM in Health Science courses, seven (n=7) in Earth Science courses and one academic (n=1) in both Health and Earth Science courses. Eight participants were teaching on Earth Science related courses, four of them contributing to an Earth Science course (Year 2) and another four to an Earth Processes course (Year 3). Other courses participants were involved with were: *Geology* (Year 2), *Practical science: physics and astronomy* (Year 2), *Planetary science and the search for life* (Year 2), *Understanding the continents* (Year 3), *Science: Concepts and practice* (Year 1), *Science and health* (Year 1), *Developing your paramedic practice* (Year 2), *Infectious disease and public health* (Year 3). Participants had varied roles in relation to teaching and learning with the VM (see Table 1). It is noted that Year 1 courses are introductory courses that aim to help and support students with starting their studies in higher education. They are taken during the first year of studies, whereas Year 2 and Year 3 are taken during the second and third years.

[Insert Table 1 HERE]

c. Method of data collection

An interview schedule (see Appendix 1) was created and piloted prior to the start of the study. The interview involved questions related to:

- the context in which the VM is being used: e.g., *'How necessary is it to access the VM to understand the content under study (supplementary use or not)?'*;
- the interviewee's perceptions on the current use of the VM: e.g., *'Do you think the experience feels realistic?'*
- suggestions for changing existing VM learning activities: e.g., *'Would you design the VM activities in a different way? What would they look like?'*
- the future use and pedagogical integration of the VM in online and distance courses: e.g., *'Would you see any other tools being used in the future replacing or complementing the VM? What would they look like?'*

d. Process of data analysis

The 12 interview transcripts, produced by a professional transcription service, were analysed using thematic analysis (Braun & Clarke, 2006). Transcriptions of the verbal content of the recordings were initially produced and the authors spent time in becoming familiar with the data by reading the transcripts. The analysis followed an inductive, data-driven approach of identifying codes and assigning themes. Initial codes were generated from the data through the use of NVivo software (www.qsrinternational.com/nvivo/home), with some content falling in more than one code. Themes were then extracted by clustering conceptually relevant codes together. Themes and codes were identified by the second author after analysing a small number of transcripts, verified and modified where necessary by the first author to ensure inter-rater reliability. The inter-rater percentage agreement reached 83%. This was calculated by dividing the number of times both researchers agreed by the total number of times coding was possible (Boyatzis, 1998). The two researchers resolved disagreements by merging codes with similar meanings into a single theme and by creating two additional sub-themes. The final emerging themes (see Table 2) are as follows: Students' benefits from using the VM, Physical microscope versus VM, Online pedagogy, and Challenges & suggestions for improvements.

[Table 2 here]

6. Findings

Table 3 presents the four overarching themes identified in the analysis, followed by the 11 sub-themes and a summary of what each theme denotes. In the next paragraphs, we provide a detailed description for each theme supported by actual quotes from the interviews.

[Table 3 here]

a. Online pedagogy

Introducing the VM: In the Earth Science modules, the VM is introduced to students through a set of activities: (a) students are asked to familiarize themselves with the VM by examining, for example, simple minerals in hand specimens using both the VM and another online tool, (b) a short training video showing students how to use the different VM functions, (c) tutorials with teachers, that is online synchronous sessions moderated by a tutor; a part of the tutorial focuses on how to identify minerals and their properties using the VM, and (d) tutor group wikis are used for reporting and communication. Other participants (Ac4, Ac9) also mentioned that the introductory activities include explanations about the science behind the Physical Microscope (PM) that precede the VM introduction, to showcase that the VM is an alternative option to using the PM.

While in Year 2 modules time is allocated to introducing the VM, there are cases of Year 3 modules where the VM is not introduced to students, on the assumption that students are already familiar with it from using it in Year 2 modules. Extra tutorial hours are provided to support students who may not have any previous experience of using the VM, yet these tutorials are not compulsory.

In a similar manner, in Health Science modules, the VM is introduced through a video and explanations about how to use the VM to identify slides. Yet, in addition to that, students are asked to engage with the VM in a more active way, by completing multiple choice questions related to VM slides: *“There’s a multiple choice question [...] we’ve given them a lot of the questions [which] are ones where we’ve taken the microscope image ourselves, put it in black and white so it’s a little bit harder to identify just from thumbnails.”* (Note: the VM Slidebox has thumbnail views of the slides; Ac1, course author)

Online VM activities: A variation in VM integration has been observed in the lifecycle of different modules; it can either occupy a specific section of the module as in an Earth Science module in which it is used, “*between a third and a half of a module*” (Ac4, course author) or be spread throughout the module as is the case of a Health Science module in which it is used across all different types of cells, “*for each type of cell and tissue [...], [students] can go on the VM and study the biological specimen*” (Ac1, course author). This suggests that specific learning objectives or content such as the study of cells can enable a distinct pedagogical integration of the VM in a given module.

Students are asked to engage with the VM as part of a learning activity. The structure of VM activities and level of student interaction vary: students may be asked to (a) read and observe, for example, rocks, minerals, and field localities, (b) make calculations, count cells, and measure data, and (c) reflect on other relevant concepts. A requirement of these activities is to calibrate the VM and work out scaling. As explained:

“I would say probably about half of them [the activities] are observation on rocks and minerals and photographs of field localities and then probably about a quarter are quantitative, so taking chemistry data and actually doing something with that – calculations.” (Ac4, course author)

In other cases, students are asked to (d) complete a learning activity as part of a tutor group wiki. As described below:

“They count the number of leucocytes in about a dozen grid squares assigned to them. Each student in a tutor group is assigned different set of grid squares by their tutor. They then add their cell counts into a tutor group wiki, so between them they have counted a large number of fields on the slide [...] They then independently analyse and present the results.” (Ac7, VM learning activity author)

VM assessment: In some of the modules, the use of the VM is part of the module assessment whereas in others its use is not assessed at all; in the latter, the purpose behind using the VM is to engage students with the material and potentially make the activities more interesting:

“None of this is assessed in any way, this is just something they can do if they want to but that makes it a little bit more interesting for the students, otherwise you might just as well give them pictures of organisms and that’s it.” (Ac5, VM learning activity author)

In modules assessing the use of the VM, this is part of the continuous module assessment in Teacher-Marked Assignments (TMAs). A TMA may require students to run an investigation that requires the use of the VM and report on their methods, results and conclusions. In other cases, the aim of the assessment may be to test the development of students’ observation skills when using the VM by presenting to them a new slide to observe and work with. As explained:

“Students do an investigation of antibody stained normal and cancerous breast tissue biopsies, comparing the number of oestrogen receptor positive cells. They have to decide for themselves how many fields to count, what to regard as a positive cell, how to present their results.” (Ac6, VM learning activity author)

“We don’t test them on their ability to name different minerals, but we test them on their ability to say I’ve got the mineral, it’s this size, it’s got this colour it does this, it has this and this and this property.” (Ac4, course author)

Tutor support and communication: The design affordances of the VLE hosting a module as well as individual actions by teachers are supporting students when they engage with the VM. In terms of the module design, module-wide and tutor forums are used as portals for students to raise questions and receive support from the module team and their tutors. These are forums that can be attended by anyone on a course (module-wide forums) or students belonging to a specific teacher group (tutor forums). As explained: *“the teachers will provide feedback and we provide feedback because for different slices of the module I’ve got different academics monitoring each forum as well as the teachers”* (Ac3, course author). Tutor forums are restricted to the students a tutor is monitoring (normally 15-20 students) and they can be used proactively by tutors to engage with students, identify and resolve any issues they may face.

Teachers were also found to exhibit ‘agency’ over and above the set social affordances of the learning design, in this case the module-wide and tutor forums; responding to learning

needs, they created their own videos with instructions about how to use the VM as well as arranging additional online tutorials. This reveals the students' need for ongoing and on-time support when using the VM. As explained:

“I know that some people wrote on the forum and said look I’ve got a problem doing this. Can you explain it to me? And because of that I made a short Camtasia video showing them how to use the scale, how to find organisms, how to do the counts.” (Ac5, VM learning activity author)

“There were a lot of students saying oh, I’m not feeling confident with my skills in the virtual microscope [...] and I don’t know if what I’m seeing is what everyone else is seeing. So we ran an impromptu session, online session, on Saturday.” (Ac3, course author)

Student support and communication: Another way of receiving support is through peer interaction and communication. Students seek and receive support from peers either in tutor forums moderated and facilitated by tutors, or in student forums, managed by students and not facilitated by tutors. The level of support depends on the traffic of a given forum and a given cohort of students; it is often common to observe “only a few loud voices” (Ac3, course author).

The use of student forums to receive and provide support may not be favoured or endorsed by some teachers. As noted by one interviewee *“this may not be a good idea as students can get a lot of different responses that can be quite confusing for them [...] and not being in a knowledgeable position to know whether the information they’re getting is reliable or not”*. This quote is revealing of the teacher’s perceptions of how learning takes place or is supported, in particular that peer learning may not be as effective as learning from experts or teachers. Similar to student forums, students make use of external social sites such as Facebook groups *“closed to staff, students only were running that”* (Ac8, member of the online course design team).

Overall, there is a need for ongoing support when using the VM, that is over and above the introductory VM activities, training videos, and tutorials. Students raise questions about the use of the VM in tutor and student forums throughout the presentation of a module and it is up to the teachers to respond and provide support. This may simply mean that teachers reply to a forum comment or create and share a relevant video. Ongoing student support is rather random and unstructured; it depends on the tutors - and whether they are proactive - as well as on the degree of peer interactions and communication.

b. Student benefits from using the VM

Engagement: According to interviewees, students engage with the VM because they find it enjoyable and easy to use. These insights came from their interaction with students in forums as well as student surveys: *“so the other students say oh, you should go and look at the virtual microscope, it’s just amazing.”* (Ac3, course author)

In other cases, students engage with the VM because it forms part of an assessed activity: *“If it’s not in the assessment they tend not to bother”* (Ac2, course author). In a module where the VM activities are not assessed, an interviewee raised the lack of insights as to whether students are engaging with the VM: *“We can’t tell whether students are actually engaging with it [the VM]”* (Ac5, VM learning activity author).

Learning: Interviewees identified benefits in the development of students’ observation skills, essential in disciplines such as Earth Sciences. The VM is considered as *“a tool for teaching skills rather than a tool for teaching facts”* (Ac4, course author), that can *“train students how to use their powers of observation to recognise different things”* (Ac2, course author). This *“is an important skill because Earth Science is very much an observational science [and] how to identify the minerals on the virtual microscope and then apply that knowledge to solving a problem and that’s the best kind of learning.”* (Ac8, member of the online course design team)

Unique value: Interviewees assigned a unique value to using the VM in online and distance learning. They perceive the VM as a means to provide hands-on, interactive science experiences to students online, that resembles the experiences of using a physical lab with microscopes. They oppose this approach to more passive ways of learning, such as reading. As explained: *“A tool to create interest and to get students feeling that they’re actually involved in science”* (Ac1, course author). They also assigned added value to the fact that, through the VM, slides can be projected on a screen, a functionality not supported by a physical microscope: *“Here’s the real microscope and here are real thin sections but we didn’t have a video camera set up onto a microscope, so in order to show students what they were looking at we’d hook through to the virtual microscope which had a similar chip of a similar rock.”* (Ac4, course author).

In terms of the practical value of the VM, interviewees perceived this as the only means available to allow students access and use of microscopy without any financial implications. It also enables access to samples not accessible in other ways such as moon samples. As explained: *“You can look at all the Apollo samples that the astronauts brought back from the moon”* (Ac9, member of the online course design team/MOOC author). Overall, the online implementation of the VM brings certain benefits to students, including those students who are facing accessibility issues and for whom the use of a physical microscope may not be an option.

c. Physical versus Virtual Microscope

Learning experience: Interviewees noted both differences and similarities in the experience of using a VM versus a physical microscope. They noted differences in the process of manipulating slides, that is the buttons used to move a slide around: *“It’s just that you have to push and pull different knobs on a real microscope rather than pressing a button on a screen”* (Ac4, course author). They also noted greater flexibility and freedom when using a physical microscope: *“But on a real microscope you can move the slide wherever you want and look at whichever bit you like and then you can rotate it as well”* (Ac3, course author).

They mentioned similarities in what students can actually see and the experience of focusing their attention or becoming immersed in a single slide, either through the screen or through the physical microscope lenses. Also, they perceived both microscopes as resulting in the same learning benefits: *“the virtual microscope is the digital version of the petrologic microscope for teaching purposes and for outreach purposes, it’s no different”* (Ac9, member of the online course design team/MOOC author).

Functionality: In terms of the functionality of the two microscopes, they perceived the VM as being easier to use by manipulating buttons on a website whereas a physical microscope requires additional training about how the tool functions, for example, how to manipulate magnification and focus or change the field of view: *“You need even more knowledge than the electronic version or the virtual version of it because in the end it’s a website with buttons to click that makes it actually easier than the real thing where you need to know which button to turn which way and which angle to set and stuff”* (Ac9, member of the online course design team/MOOC author). Also, the VM allows students to get an automated measurement of distances on a slide by manipulating the online functionality.

Teaching: The VM allowed teachers to better monitor and scaffold their students' interactions with the slides and also integrate the VM in assessment activities. A huge advantage of using the VM for teaching is *“being able to see exactly what the student can see”* (Ac8, member of the online course design team) in contrast to the physical microscope where every student gets a different thin section. With all students getting the same image the VM can be used *“for a far more uniform assessment for all the students”* (Ac2, course author).

Other advantages of the VM include *“training students to develop online, on-screen skills”* (Ac4, course author), the ability to *“add labels to the slides”* (Ac12, tutor of students/MOOC author), and also greater time spent on teaching about the slides rather than training students how to use the microscope.

Other resources: The VM presents advantages compared to a physical microscope. A physical microscope requires resources such as money, time, and effort to send physical microscopes to online students, including the high costs of making the thin sections, buying the microscopes, getting them checked, and packed as well as the fact that the actual slides may contain artefacts that may prevent the viewing of the actual image. Further to that, interviewees commented on the fact that the physical microscopes are highly sophisticated optical instruments that can be easily damaged in the post, and they frequently need service.

d. Challenges to online pedagogy

Learning challenges: Interviewees commented on a number of learning challenges related to the use of the VM. They raised the issue of inadequate support when students interact with samples online, that may not help them to identify elements on a slide, dissolving possible misconceptions, and raise additional questions and answers through discussion with the teacher and peers. Contrasting learning with the VM to learning in residential, face-to-face conditions, an interviewee explains:

“But I think the thing with the residential school because they’ve got tutors on hand to tell them they learn so much quicker because it’s a lot more efficient because they’ve got somebody there just to say ‘oh no, that’s a hole in the slide’ or ‘that’s a bubble in the resin’ or this, that and the other [...] they’ve got peer support as well because they’ve got other students alongside them and they usually share microscopes.” (Ac3, course author)

They also made a special reference to students who lack skills and confidence when studying online and who are less likely to get in touch with the teacher to raise questions and help themselves understand what the VM slides show. These observations relate to a broader identification that supporting students in online distance learning settings is harder than in face-to-face learning, where a teacher can observe what each student is doing and intervene the moment a student may need help.

Technical challenges: A technical challenge reported in particular by Earth Science teachers was that the VM rotation points are fixed, making it difficult to identify what students are looking at in a given moment. Other interviewees made reference to limitations due to magnification: *“You can’t go to a higher power magnification like you can on a real microscope”* (Ac12, tutor of students/MOOC author). Some other limitations reported were not directly related to the VM, but the hardware students use and the software needed for it to function: *“so although we might say look for this colour and then it’ll change to that colour, it’s not always that colour on the monitor or device they’re looking at”* (Ac11, tutor of students).

e. Suggested improvements

Interviewees presented a range of ideas as to how the online pedagogy around the VM could be improved. These are related to technical/usability and teaching improvements.

Proposed technical improvements: Teachers suggested improvements in the resolution of sample images (Ac4, course author), proposed the addition of a pointer to show students what a teacher is pointing at (Ac12, MOOC author), an increase of the reference collection in relation to a specific mineral (Ac11, tutor of students) and the addition of functionality for sending screenshots to the forum (Ac1, course author). With regards to the Earth Science VM, they proposed the integration of a microprobe that would make the images interactive (Ac3, course author), the addition of more rotation points (Ac3, course author) and the addition of a rectangular field view (Ac8, member of the online course design team).

Proposed pedagogical improvements: Several suggestions were made as to how to improve the pedagogy around the VM. In particular, teachers proposed:

- that VM activities request students to draw the VM image on a piece of paper, as a means to recall what they are seeing on the screen: *“look away from the screen and*

remember what they just have seen to put the line on paper” (Ac9, member of the online course design team);

- the implementation of synchronous online hands-on labs facilitated by tutors during which students complete activities using the VM: *“if they have any questions they can just ping a question to the tutor in a bit like a demonstrator in a practical session in a face-to-face university”* (Ac4, course author);
- the integration of additional learning objectives when using the VM, over and above counting and measuring, such as comparisons across slides: *“something to do with measuring, counting, looking for associations”* (Ac5, VM learning activity author);
- access to satellite images from, for example, Google maps: *“you can invite the student to create their own geological map with these resources”* (Ac2, course author) and networked physical microscopes: *“Students from outside can actually be looking on a real microscope in real time and moving around and looking at stuff”* (Ac5, VM learning activity author).

Finally, teachers noted that they should be engaged with the process of designing activities with the VM: *“they’re better equipped to give students the best possible learning experience”* (Ac8, member of the online course design team).

7. Discussion

The pedagogically-sound integration of digital tools in courses is a significant or core consideration of technology-enhanced learning (Lillejord et al, 2018). A well-designed course can facilitate and scaffold learning, especially in online settings where learning is mostly autonomous and self-regulated. In this study, we considered the pedagogy around the use of the Virtual Microscope (VM) in Health and Earth Science courses at an online and distance university. The aim was to identify what works and what does not in order to improve the students’ learning experience. We conducted 12 semi-structured interviews with teachers involved in the design of online courses and communication with students. Engaging teachers in the process of research and course evaluation can be a valuable source of information due to teachers’ unique insights from their interactions with students and their involvement in the delivery of learning.

As reported by teachers, the way the VM has been integrated into the learning design of Health or Earth Science courses varies (RQ1). Aligning with other studies (Herodotou, Muirhead et al., 2018), there is not yet an agreed best practice as to how to engage students with the VM and this is evident in the diversity of VM learning activities, ranging from rather

simple ones (observing, identifying and classifying) to more complex ones (calculating and conducting an investigation using the VM). Similarly, the degree to which students have opportunities to interact with the VM depends on whether this is used systematically throughout a course presentation or in specific parts of a course, as well as whether engagement with the VM forms part of the course assessment or is perceived as an add-on aiming to foster participation. In terms of student support, this is not explicitly structured in the lifecycle of courses, with the exception of introductory activities (tutorials, videos, and written instructions) about how to use the VM. There is a need for ongoing and on-time support evidenced in the fact that students tend to raise questions about the VM in both the tutor and student forums. This shows the students' need for support while using the VM, also reported in Herodotou, Muirhead et al., (2018). In response to that need and in addition to forum responses, some teachers proactively support students by creating relevant videos.

Teachers reported several benefits from using the VM in teaching (RQ2) both for students and the teaching practice, confirming studies that reported satisfaction and enthusiasm when the VM is used in teaching (Brown et al., 2016). In terms of students, they perceive it as a means for engaging students with online material that can result in certain learning benefits. It can reinforce students' understanding of microscopy to identify minerals and textures or cells and patterns, contribute to the development of observation skills, essential in disciplines such as Health Science and Earth Science, and help build other "online" skills such as adding labels to slides. It also gives access to unique learning opportunities (e.g., viewing moon rock samples or pathology tissue samples) not accessible in other ways. In terms of teaching, the VM can provide hands-on, interactive, science experiences with no added financial cost to students who study online and who cannot have access to a physical microscope. It can also free teaching time for use in other activities as students do not need extensive training about how to use the VM (compared to using a physical microscope). Further, it becomes easier for teachers to monitor what their students are observing when using the VM as they all share the same slide view, a technical feature that makes the VM suitable for use in assessment.

Apart from perceived benefits, certain challenges related to pedagogy and technology were mentioned. Teachers stressed the issue of inadequate support when students interact with samples online. The lack of sufficient support may result in not correctly identifying elements on a slide and dissolving misconceptions, and sparking further questions and discussion. The current teaching model is that students should get in touch with their teachers when they have questions. Yet, there are students who are not confident enough or who are not used to contacting their teachers and who may never request support. The challenge with

using the VM is that teachers cannot observe what students are doing with it and intervene when they need help. Other challenges were technical in nature and referred to the rotation points that are fixed, labelling, magnification as well as hardware and software requirements such as the colour calibration on different computers.

Answering RQ3, teachers provided a rich account of how to improve the pedagogy around the VM, showcasing that (a) certain changes are needed to improve the overall learning experience and cherish the benefits from using the VM in online settings, and (b) teachers should be engaged in the design or redesign of courses in a co-creation capacity as their experience of teaching and interacting with students can be informative. Proposed improvements to VM pedagogy were related to (1) supporting students throughout the course presentation through, for example, synchronous online hands-on labs, and (2) improving the design of VM activities by addressing a range of learning objectives, not only reading, viewing, counting and measuring, but also for example, making cross-slide comparisons and promoting the development of metacognitive skills. Finally, VM activities could be linked to contextualized or place-based learning by using satellite images and making use of networked physical microscopes. This suggestion aligns with studies that showed enhanced learning benefits when the VM was combined with a physical microscope (Becerra et al., 2018). In terms of technical improvements, teacher suggestions were either related to usability improvements such as better image resolution, addition of rotation points and a pointer, and update of software, or additional functionality that can support learning such as increasing the reference collection, adding a function that allows sending screenshots to a forum, and integration of a microprobe that could make the images interactive.

The findings discussed above have emerged from a rather small group of teachers who work at a single distance learning higher education institution. Given the fact that this paper reports on a single case-study, outcomes should not be generalized or transferred to other contexts or institutions, rather they should be used to inform the design of follow-up studies. Such studies should use insights from this study, such as teachers' suggestions for improvements or reported student difficulties, to redesign selected VM activities and capture their impact on student learning. An experimental or quasi experimental design could answer research questions including (a) Does additional synchronous support by teachers when students are using the VM result in better learning outcomes? (b) Does built-in feedback integrated in the design (interface) of the VM enhance student interactions and understanding? (c) Do inquiry-based activities that require students to use the VM facilitate understanding?.

8. Conclusions

The role of teachers in online and distance education is considerably different to that of teachers in blended or face-to-face educational settings. In conventional, face-to-face teaching, a single teacher is often responsible for the design and implementation of the lesson plan and associated learning activities, the provision of student support and allocation of marking. In contrast, at The Open University, teachers form part of larger groups of specialists and contribute to two main processes: the production and the presentation of a course. Participating teachers were involved in the course production and presentation, authored content and learning activities related to the VM and communicated with students in forums. Two of them also engaged with students face-to-face in residential schools while another two acted as student teachers supporting a group of students, correcting assignments, and running synchronous tutorials.

This division of labour has implications in relation to: (a) how changes to the online provision are made in response to students' needs, and (b) teachers' ownership of teaching material. While in traditional teaching, a teacher can modify their teaching or learning activities to accommodate students' requirements by, for example, offering additional explanations, elaborating further on hard-to-grasp issues or redesigning a learning activity, this is less likely the case in online settings where the provision is relatively stable and rigid and the role of the teacher is mainly that of supporting students when they interact with a set of predefined learning activities. These conditions can also be a threat to teachers' agency or ownership of teaching evidenced in responding dynamically to students' needs and making alterations or additions to learning activities during or after a course presentation. What this paper suggests is that teachers should be engaged in the process of learning design in alternative ways, as experts in the science of teaching or as "design researchers" (Persico et al., 2018). The teachers' voice or experiences from teaching on a given presentation should be systematically reviewed and considered in the evaluation and redesign of a course. This process should be seen as a continuous professional development activity that aims to improve online pedagogy. It should be an opportunity for teachers to reflect on their own teaching practice, learn from each other and contribute to enhancing teaching and learning online.

The process of engaging teachers as researchers in online course design can facilitate innovation in teaching. Innovation should be viewed as a problem-solving process and as an integral part of teachers' professional identity, rather than an add-on activity enacted by a few

teachers and at some institutions (Paniagua & Istance, 2018). In this study, participating teachers proposed certain pedagogical innovations about the use of the VM in online courses related to: (a) the design of learning activities and (b) the provision of student support. They proposed improvements to the VM learning activities that can accommodate a range of learning objectives, not only reading, viewing, and measuring but also comparing and reflecting. This finding aligns well with existing work showing that assimilative (read, listen, view information) and assessment activities are more prominent in online courses than other types of activities, such as finding and handling information, communicative, productive, experiential, and interactive activities. Yet, an emphasis on assimilative activities is more likely to lead to lower student completion and pass rates (Rienties et al., 2015). Follow-up studies confirmed the importance of learning design in predicting students' performance and VLE behavior (Rienties & Toetenel, 2016). These findings raise the need for redesigning learning activities to meet a range of learning objectives and, in the case of VM, to promote the development of higher-order metacognitive skills.

The second innovation teachers proposed is related to effective student support throughout the course presentation that would help students understand what they view on slides, dissolve possible misconceptions and elaborate further on their understanding. This aligns well with existing studies on learning design showing that activities that focus on communication and productive engagement, rather than assimilative tasks, can improve student performance (Rienties & Toetenel, 2016). They also reaffirm students' perceptions about the VM and the need for additional tutor support that would confirm their understanding of VM slides (Herodotou et al., 2019).

Insights from this study suggest that future work should focus on redesigning and evaluating VM learning activities in such a way that students could better engage with others, receive support, and develop higher-order thinking skills. Any design innovation in teaching and learning should consider the students' "natural learning inclinations" for play, creativity, collaboration and inquiry (Paniagua & Istance, 2018, p.30). One example of how a VM activity could be redesigned is by integrating the VM in authentic scientific investigations (Herodotou, Sharples et al., 2018; Herodotou et al., 2021) in which students are asked to participate in all the stages of the scientific method – from setting up their own research project to identifying certain elements on a slide as a means to answering a bigger research question, sharing and discussing their ideas with other students, reflecting on different perspectives and consolidating ideas with the support of teachers who are experts in the topic. Also, future studies should seek to examine and address concerns as to whether the online

only implementation and use of the VM may have a negative impact on students' skill development (Rivera, 2016), specifically the skills to operate a physical microscope.

Although conducted prior to the Covid-19 pandemic, this study emphasizes the significance of virtual tools such as the VM for the creation of sustainable models of education (European Commission, 2021), that are bullet-proof to potential disruptions such as a pandemic or travel restrictions due to climate emergency. One of the major challenges faced during the pandemic was the implementation of practical science work such as access to laboratories and field work. In response to that, different methods of teaching were trialed including remote access to lab equipment and take-home kits, the latter endorsed by students for use post-pandemic (Bishop et al., 2021). At The Open University, the VM is only one of the tools available to facilitate practical science work from a distance, with the Open Science Lab (<https://learn5.open.ac.uk/course/view.php?id=2>) hosting further tools such as virtual reality field trips, remote operation of optical telescopes in Tenerife, and interactive screen experiments. Such tools provide teaching and learning flexibility and could support learning, not only from a distance but also face-to-face by, for example, enabling students to access tools in their own time and place thus complementing their learning. The design of pedagogically robust VM activities as suggested in this paper should be seen as an example of how technological and pedagogical innovation could contribute to a resilient post-pandemic education (Whitelock et al. 2021).

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