Students as virtual scientists: a review of remote microscopy use in education

G. Childers and M. G. Jones

Department of Science, Technology, Engineering, and Mathematics Education, North Carolina State University, Raleigh, North Carolina

Remote microscopy laboratories enable precollege students to investigate science by using scientific tools, such as a scanning electron microscope, and communicating in real-time with scientists and researchers with only a computer and an Internet connection. Because of this unique learning experience, students can become virtual researchers by collecting and submitting data, operating scientific tools, and collaborating with scientists. The use of technology applications, such as remote microscopy, can promote student learning, motivation, and preparedness for the future workforce. Although the implications for using remote microscopy investigations in education could be significant for student learning, research is limited in number and scope; however, there are studies that investigate student learning and experiences with remote microscopy. During remote investigations, students are able to develop experiments and engage in scientific inquiry. Remote learning environments have the potential to engage students in science because technology use in science classrooms has been shown to increase student interest in science and academic achievement. Understanding how students interact with remote microscopy investigations is crucial for the development and maintenance of remote microscopy education programs. This chapter reviews research on remote microscopy tools in K-12 classrooms and provides insight into the benefits and limitations of remote microscopy technologies use in education.

Keywords: remote microscopy; science education

1. Introduction

The use of microscopes in precollege classrooms is often based on traditional methods of teaching science concepts and microscopy. Typically, students begin their learning journey by memorizing the parts and functions of a light microscope. Students often look at prepared slides provided by the teacher, or students may create wet mounts to view and record structures of living organisms such as plant cells. In this scenario, while students often are able to document their observations, students rarely are afforded the opportunity to pose questions and investigate science phenomena through the use of microscopes [1]. Additionally, depending on the financial resources of the school, students may only have access to a limited number of functioning microscopes or sometimes only a diagram of a microscope on paper.

However, new computer technologies now allow students to investigate science in novel ways such as remotely accessing telescopes to explore astronomical and scale concepts or scanning electron microscopes to learn about viruses [2,3,4]. Remote access technologies offer unique learning experiences and enable students to use scientific tools and communicate in real-time with scientists anywhere in the world. Students, for the first time in history, can become virtual researchers in an array of science laboratories. As a consequence of this access, the utilization of remote microscopy tools in classrooms has emerged as a research focus because students are able to contribute, view, and analyze scientific data within remote learning environments.

The effectiveness of remote access laboratories has rarely been investigated [5,6]. Although research regarding remote access laboratories exists, many of the studies describe the development and implementation of remote laboratories in the field of engineering rather than focusing on educational factors associated with learning, motivation, and student identity [5,6]. In addition, the remote access technology that is available is heavily biased towards engineering disciplines and college-level students [6]. Ma and Nickerson [6] have noted that engineering remote laboratories are growing in popularity because they allow college-level students to develop technical skills.

2. Research on Remote Microscopy Tools in K-12 Classrooms

In general, laboratories are essential to science education, as they offer science experiences and teach critical skills [7,8]. In addition, science educators have advocated for hands-on experiences in classrooms [2]. Currently, many laboratories have been transformed into computerized and simulated experiences, effectively changing how laboratory work is implemented in science courses [9]. However, debates have emerged as to whether face-to-face laboratories are more conducive to science learning than simulated or remotely accessed laboratories.

According to Corter, Esche, and Chassapis [10] and Ma and Nickerson [6], there are mixed, complex results in interpreting the benefits of face-to-face, simulated, and remotely operated laboratories indicating that the effectiveness of simulated and remotely operated laboratories may be dependent upon social and motivation factors, and how those new technologies are implemented in the course. Furthermore, research suggests that students are more motivated while using remote access laboratories, and remote access laboratories are more effective than simulations [9]. However, most studies of remote access technology literature focused on student conceptual learning and professional skills as compared to hands on laboratories and simulations that emphasize conceptual, design, and professional skills [6].

Remote learning environments bridge the traditional gap between hands-on laboratories and computer simulations by providing students the opportunity to do real investigations at a distance from a scientific laboratory. There are remote programs for students in K-12 science classrooms (*e.g.* Bugscope); however, there are only a few studies that explore the impact of these technologies on student learning and experiences. Although research in remote learning environments has been limited in scope and depth and often focused on development and evaluation of remote tools, there are a limited number of studies that investigate learning and student experiences in conjunction with remote microscopy utilization in K-12 classrooms. Table 1 highlights existing studies.

Jones, Andre, Kubasko, Bokinsky, Tretter, Negishi, Taylor, and Superfine [3] investigated 209 high school and middle school students‘ understanding of viruses using a remote atomic force microscope in conjunction with varying degrees of haptic experiences (full haptic experience touch and force feedback sensory information and haptic joystick receiving only tactile sensory responses). The students in the study received five days of instruction that provided an overview of nanotechnology and size and scale, a training session on how to use the nanoManipulator (haptic device) and the remote atomic force microscope program interface, and enabling students to investigate the structures of viruses using the aforementioned tools. The study showed that there were significant gains from pre to post time periods for all students in relation to attitudes, knowledge of viruses, development of conceptual models, and understanding of scale. However, students that had the full haptic experience reported significantly higher attitudes (students' reactions and experiences with using an atomic force microscope) than the other groups, which may suggest that the overall haptic sensory experience may have been more engaging and motivating. Jones et al. [3] speculated that providing tactile experiences in conjunction with remote microscopy could be beneficial for students with a wide range of cognitive abilities by providing multisensory experiences.

Another related study conducted by Jones, Andre, Superfine, and Taylor [2] studied 50 high school students' understanding of viruses utilizing a remote atomic force microscope and a haptic device in which students' knowledge of microscopy, scale, and knowledge of viruses changed as a result of the students' experiences. While the focus was on the haptic feedback devices, the researchers' suggest experiences with technology may be beneficial to students' engagement, motivation, and learning of science concepts. Jones, Andre, Superfine, and Taylor [2] noted that although incorporating remote microscopy into high school science classrooms is feasible, there is a need for more research on the educational uses of remote microscopy in science classrooms.

A series of studies by Childers [11] and Childers and Jones [12,13] studied 72 high school students' perceptions of motivation to do science (*I want to do this investigation*), science identity (*I am a science-oriented individual*), virtual presence (*How real is the investigation?*), and ownership (students pre-selected their insects and students that did not pre-select their insects) along with measuring students' knowledge of insect structures and microscopy during two remote scanning electron microscopy sessions. The web-based program allowed the high school students to direct the scanning electron microscope to view a chosen insect and manipulate the image, change the focus and magnification, and communicate with scientists in real-time through an online interactive chat module. The study showed that there were significant gains in students' knowledge of insect structures and microscopy and students' perception of science identity from pre to post assessment periods; however, there were no significant changes in students' perception of motivation to do science [11,12]. Students that pre-selected their insects for investigation were reported as being significantly less distracted during the remote microscopy investigation than the control group that viewed a class insect. Overall, all students reported high level of virtual presence reporting the remote microscopy investigation was *very real* even though the investigation was mediated by the computer and Internet [11,13]. Childers and Jones [12,13] noted that there is a need for future studies to investigate other factors that contribute to successful remote investigation experiences for students, such as students' perception of engagement, how perceptions of *ownership of data* influence student interactions, how remote technology is incorporated into science classrooms, and the efficacy of remote technologies as a tool in K-12 environments to ignite an interest in science.

Table 1 Description of studies involving precollege students' investigations with remote microscopy

Article	Remote Microscopy Tool	Participants/Sample Size	Findings
Jones, Andre, Kubasko, Bokinsky, Tretter, Negishi, Taylor, and Superine [3]	Atomic Force Microscope and nanoManipulator	Middle School and High School Students (*n* = 209)	Significant changes in students' understanding of scale, identification of nano-sized objects, and development of conceptual model of viruses.
Jones, Andre, Superfine, and Taylor [2]	Atomic Force Microscope and nanoManipulator	High School Students (*n* = 50)	Significant changes in students' understandings of microscale, virus morphology, and dimensionality (change of students' concepts of a 2D to a 3D virus model).
Childers [11] and Childers and Jones [12,13]	Scanning Electron Microscope	High School Students (*n* = 72)	Significant changes in students' perceptions of science identity and knowledge of insect structures and microscopy; students reported the remote microscopy investigation as being *very real*. No significant changes in students' perceptions of motivation to do science.

3. Benefits and Limitations of Remote Microscopy in Classrooms

Understanding the limitations and benefits of remote technologies can help shape the development and implementation of new remote programs. Overall remote technologies, such as scanning electron microscopes, allow students and teachers to access real scientific tools and to communicate with scientists through a network or Internet connection [5,6]. Different scientific tools can be remotely accessed so that the tools can be shared among many schools allowing students to have greater accessibility and opportunities to gather and analyze scientific data. Childers and Jones [11,12] research captured high school science teachers' perception of benefits in using a remote microscopy tool in their classroom. The teachers stated that remote technologies are great educational tools that enable students to explore scientific concepts in a novel way and helps limit the costs of not having to fund a fieldtrip or buy expensive equipment to do science in the classroom. Additionally, the teachers stressed the importance of student access to microscopes and scientists. They indicated that most students in their classrooms have never talked to a scientist before or used research-grade microscopes in school. The teachers specified that remote investigations may inspire the students to continue to pursue their interests in science [11,12].

There is evidence that remote investigations teach the science process skills: observing, questioning, collecting and analyzing data, and interpreting results [5]. Lowe, Newcombe, and Stumpers [5] researched students' understanding of remote access technologies in grades 9-11 in Western Australia. Results from this investigation showed that students perceived remote access technology to be a valid practical experience in obtaining and reproducing data. Remote learning environments have the potential to engage students in science in innovative ways since technology use in science classrooms has been shown to increase student interest in science as well in academic achievement overall [14]. Although there are numerous potential benefits of using remote technologies in classrooms, limitations of remote technologies in K-12 science classroom settings have been noted [15]. These limitations include:

1. A lack of time for teachers to include a remote microscopy session in their structured curriculum.
2. Teachers may not have the skills and/or knowledge to use computers, the internet, and remote technologies such as a Scanning Electron Microscope (SEM).
3. Teachers may not have access to equipment or technical support.
4. Teachers may not see the value of incorporating a remote microscopy session in their instruction.
5. Scientists and researchers controlling the SEM may not have time to educate K-12 teachers to effectively use the program and tools in the science classroom.
6. Partnering scientists may know very little about the K-12 curriculum [15].

Childers' [11] and Childers and Jones' [12] studies of remote use of SEM with high school students found that remote technologies were perceived as virtual environments by teachers who found the remote investigations limiting for student interactions. The teachers believed a main constraint of a remote microscopy investigation is that the experience was not very interactive for the students and reported they preferred the students to have one-on-one interactions with the remote microscopy tool and the scientists. However, it was noted that the teachers understood that having one-on-one interactions with the technology and the scientists would be time consuming and resource-limited [11,12]. Time limitations of using remote microscopy are found as a constraint of using remote tools in K-12 classrooms [16]. Because of these issues, Chumbley and Chumbley [16] maintain that the use of the remote microscopy tool, WebSEM, is often associated with low requests to use the remote microscope and the science lessons developed by educators in conjunction with the use of remote investigations were simple and lacking in depth [16].

To combat these issues, Chumbley et al. [15] suggested training teachers and in-service teachers how to appropriately use remote technologies in science classrooms and providing guidance on effective communication skills between teachers and scientists. Chumbley and Chumbley [16] also advocated for teachers and SEM operators/scientists to establish a *personal relationship* to effectively have access and use remote microscopy in precollege classrooms. Additionally, another strategy to facilitate learners with these new tools is to alter the science curriculum to accommodate the use of remote technologies [5].

4. Conclusion

According to the Next Generation Science Standards, there is a push for students to understand the interdependence of science, engineering, and technology disciplines in which technology enables scientific discoveries by scientists and engineers [17]. New technologies are likely to alter how society will interact with scientists in the future and as a result there is a need to prepare students to use new tools of inquiry. Because of the new advancements in technologies that will affect how society interacts with the environment, teachers need to prepare students to be effective, science-educated individuals that will be able to make evidence-based decisions on the future of the impact of technology in the world [18]. Additionally, because microscopy tools are becoming more sophisticated, the future trajectory of microscopy use in precollege science classrooms may challenge educators how to effectively use microscopy tools in the classroom and reevaluate the structure of science curricula. There is a need to continue research to better understand how and when remote microscopy is most effective in K-12 classrooms. Remote microscopy has the potential to provide inexpensive opportunities for students in low wealth areas to have high quality science experiences. No longer do students have to live near a university to experience the excitement of new forms of microscopy.

References

[1] Benedis-Grab G. Making art with microscopes. Science Scope. 2011;35(2):36-41

[2] Jones M, Andre T, Superfine R, Taylor R. Learning at the nanoscale: the impact of microscopy on concepts of viruses, scale, and microscopy. Journal of Research in Science Teaching. 2003;40(3):303-322.

[3] Jones M, Andre T, Kubasko D, Bokinsky A, Tretter R, Negishi A, et al. Remote atomic force microscopy of microscopic organisms: technological innovations for hands-on science with middle and high school students. Science Education. 2003;88(1);55-71.

[4] Lubin P, van der Veen J. The remote access astronomy project: an example of a university/high school cooperative effort. Education & Computing. 1992;8:79-82.

[5] Lowe D, Newcombe P, Strumpers B. Evaluation of the use of remote laboratories for secondary school science education. Research in Science Education. 2010;43(3):1197-1219.

[6] Ma J, Nickerson J. Hands-on, simulated, and remote laboratories: a comparative literature review. AMC Computing Surveys. 2006;38(3):1-24.

[7] Hoffstein A, Lunetta V. The laboratory in science education: foundations for the twenty-first century. Science Education. 2004;88(1):28-54.

[8] Clough M. Using the laboratory to enhance student learning. In: Bybee, R, editors. Learning Science and the Science of Learning, Washington, DC: National science teachers Association; 2002. p.85-97

[9] Scanlon E, Colwell C, Cooper M, Paolo T. Remote experiments, re-versioning, and re-thinking science learning. Computers and Education. 2004;43:153-163.

[10] Corter J, Esche S, Chassapis C, Ma J, Nickerson J. Computers and Education. 2011;57: 2054-2067.

[11] Childers G. Ownership of data: students' investigations with remote electron microscopy [dissertation]. Raleigh (NC): North Carolina State University; 2014.

[12] Childers G, Jones M. Remote learning environments: investigating students' perceptions of motivation, identity, and ownership during a remote microscopy investigation. Forthcoming 2014.

[13] Childers G, Jones M. How real is my insect?: exploring high school students' perception of virtual presence during a remote microscopy investigation. Forthcoming 2014.

[14] Walsh J, Sun J, Riconscente M. Online teaching tool simplifies faculty use of multimedia and improves student interest and knowledge in science. CBE-Life Sciences Education. 2011; 10:298-308.

[15] Chumbley L, Hargrave C, Constant K, Hand B, Andre T, Thompson E. Project ExCEL: web-based scanning electron microscopy for K-12 education. Journal of Engineering Education. 2002;91(2):203-210.

[16] Chumbley A, Chumbley L. WebSEM: an assessment of K-12 remote microscopy efforts. Scanning. 2007;29:20-26.

[17] The Next Science Generation Standards. Science, technology, society, and the environment. (2013). Appendix J of the NGSS Release. Available from: http://www.nextgenscience.org/sites/ngss/files/APPENDIX%20J_0.pdf

[18] Bybee R, Fuchs B. Preparing the 21st century workforce: a new reform in science and technology education. Journal of Research in Science Education. 2006;43(4):349-352.

