

Applying Low-Cost Sensors to Improve Students' Blended Learning Experience During the Pandemic

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Abstract: The Covid-19 pandemic has caused unprecedented disruption to global education. In particular, the laboratory and field teaching has been heavily affected by the pandemic due to the implementation of lockdown and social distance. Schools and universities had to take urgent and necessary measures to transform traditional face-to-face education to online or blended mode. Most of the measures are concentrated on tool-based pedagogy, and instructors use nearly all available tools, primarily digital tools, for example, Zoom and MS Teams, to maintain the continuation of education. The online learning, through lecturing and supervising of some processes, can build up students' theoretical aspect (knowledge), but students' practical skills have been little developed. Given the advantage of the Internet-of-Things (IoT), low-cost sensors have been increasingly used for direct measurement without laboratory support, while their application in teaching and learning has been little explored. In this case study, a low-cost air quality sensor, PlumeLabs Flow 2, was applied in blended learning of undergraduate Environmental Science/Engineering programmes. With some lectures on environmental pollution knowledge, students studied in teams (Team-Based Learning) using low-cost sensors to measure air quality and developed projects (Project-Based Learning) to mitigate environmental pollution. Survey and interviews were conducted to understand students' learning experience and identify suggestions for further improvement of this kind of blended learning. The survey and interviews indicate that more than 90% of students praised the positive effects of this new technology-enhanced learning, including improvements in skills and employability. Especially, students emphasized the advantage of learning knowledge and developing practical skills without relying on laboratory, which was very difficult or impossible during the pandemic. One of the concerns of low-cost sensors is the possible bias of the measurement data. Thanks to the rapid advance during the pandemic, online and blended learning will continue to develop in the post COVID-19 era. Using low-cost sensors will be an important approach to compensate for the lack of training of practical skills in blended and online education.

Keywords: blended learning, low-cost sensor, team-based learning, project-based learning, practical skills

1. Introduction

The rapid spread of coronavirus (COVID-19) has interrupted education systems in almost all countries. Like all organisations, universities had to instantly deal with the imminent threat from the unexpected and disruptive COVID-19 pandemic, so-called crisis management. Constrained by lockdown and social distance, universities had to take urgent and necessary measures to transform traditional face-to-face education, including field and laboratory teaching, into online or blended mode (Dhawan, 2020). The process-oriented strategy focuses on the impacts of the crisis on universities and the tasks required to perform to avoid or minimize such impacts. The term "crisis pedagogy", a crisis-aware education that includes the design and delivery of educational activities to better support learners through the crisis period (Khanal, 2021), is increasingly applied to illustrate the emergency online teaching and education task that was adopted to reduce the damage of the COVID-19 pandemic on university education. In general, crisis pedagogy consists of two parts: instructor-guided synchronous teaching and student self-paced asynchronous study. Most of the measures are concentrated on tool-based pedagogy, and instructors apply almost all available tools, mainly digital tools to continue teaching. As Nel and Marais (2020) have suggested, the appropriate teaching approach in this education crisis period should be process-based pedagogy, with the focus on how students access the study materials both safely and reliably.

For many programmes, such as Biology, Medicine, Geography, and Environmental Science/Engineering, the learning outcomes emphasize the significance of developing both theoretical and practical aspects (Gamage et al., 2020). In terms of establishing these practical aspects, students learn the field and laboratory methods and synthesise field observations and experimental practices. Field and laboratory teaching provide unique opportunities to develop students' design, analysis, problem-solving, data-recording, experimental, and practical skills (Davies, 2008). In a properly designed laboratory teaching session, students will become familiar with equipment and techniques. Learning under the supervision of teachers and in collaboration with classmates, students will be able to develop communication and interpersonal skills. By studying the real problem in the world, students can integrate learned theory with daily practice.

Most crisis pedagogy adopts an online education model. The online learning, through lecturing and supervising of some processes, can build up students' theoretical aspect (knowledge). The online learning has been increasingly used during the COVID-19 pandemic. These virtual sessions are helpful in increasing learners' understanding of knowledge, with the advantage of overcoming health and safety constraints (Lewis, 2014). However, online learning has obvious weaknesses that can affect the development of students' practical skills. Virtual laboratories, a computer-assisted learning environment which helps students perform experiments in a virtual learning environment using the computer-based interface, have developed rapidly during the COVID-19 pandemic (Kapilan et al., 2021). Notably, students still cannot directly use the equipment in the laboratory in the virtual laboratory environment, losing valuable hands-on exposure to these facilities and lacking the immersed learning experience in field and laboratory classes. The guideline for Practice and Lab-based Assessment from UK Quality Assurance Agency (QAA) states the learning outcomes need to include the assessment of competence and skill in using relevant equipment (QAA, 2020).

During the lockdowns and university closure period, instructors lack the luxury of physical tools and support, particularly laboratory and advanced equipment. For the crisis pedagogy during the COVID-19 pandemic, technology plays an increasingly important role in education, including remote and blended learning, at least offering learners access to new study materials. The new technological resources mainly used in the author's teaching include Zoom, MS Teams, Stream, Blackboard Ultra, Menti, Kahoot, and Padlet. Clearly, online education heavily relies on new technologies. After the partial lifting of the COVID-19 lockdown, students started to return to campus. However, 2-metre social distancing was still implemented in most study environments, especially laboratories. This limited laboratory capacity still constrained students' hands-on learning experience in laboratory.

In the last decade, the rapid development of the Internet-of-Things (IoT) and the maker movement promoted the accelerated advancement and wide application of low-cost electronic sensors (Chan et al., 2021). Portable and low-cost sensors are fostering appealing research opportunities. For example, low-cost bioacoustic sensors have been used to monitor wildlife and biodiversity (Teixeira et al., 2019). The build-it-yourself low-cost sensors provide opportunities to collect both spatially and temporally finer-scale data (Horsburgh et al., 2019). Low-cost sensors have also been used for large-scale hydrometeorological monitoring networks, for example, Trans-African HydroMeteorological Observatory (www.tahmo.org) and FreeStation initiative (www.freestation.org). One of the exciting advantages of low-cost sensors is that they allow direct measurement, without laboratory experiments using complicated equipment. Considering the impossibility of laboratory access during the COVID-19 lockdown period and reduced laboratory space due to 2-metre social distancing, this is extremely important. Despite their increasing popularity in research, low-cost sensors have been rarely used in teaching. In this research, a low-cost air quality sensor called Plumelabs Flow 2 was used in the author's teaching.

Despite the importance of new teaching and learning tools, students' mental health students should never be ignored (Teräs et al., 2020). During the isolated online learning condition, students need a learning environment to interact with staff and other students more than ever before, with some sense of engaging with classmates and instructors like in an in-person learning environment. One of the aims of crisis pedagogy is to engage all learners during the education process by building up some sense of students' community, which has been proved to be crucial in mimicking the in-person study experience (Khanal, 2021). To create and maintain an active student learning community, the team-based learning (TBL) was applied in the author's teaching (Michaelsen et al., 2011). Students are divided into several small groups and conduct learning together, with proper social distancing.

The overall research question is "How did the application of low-cost sensors improve students' blended learning experience during the COVID-19 pandemic?". The main aims of the research are to 1) analyse the contribution of learning using low-cost sensors to developing students' practical skills; and 2) estimate the influence of learning using low-cost sensors on promoting a learning community during the pandemic. The results will be useful to understand the value of the recently developed low-cost sensors in blended learning, even in the post COVID-19 era.

2. Research methods

2.1 Pedagogic design

In this research, a low-cost air quality sensor Flow 2 was used in the author’s teaching module Air Pollution and Urban Air Quality, with 27 students. Before the COVID-19 pandemic, students could easily access laboratories and conduct field and laboratory learning. However, online education, due to campus closure, ruled out the possibility of in-person field and laboratory learning. The blended learning began in September 2021, with the partial lifting of the COVID-19 lockdown, opened the opportunity for field class, while the 2-metre social distancing policy makes laboratory teaching still challenging. To overcome the difficulty, the low-cost Flow 2 sensor was applied in the author’s teaching.

Students studied in small groups with 3 - 4 classmates in each team (Team-Based Learning) (Michaelsen et al., 2011) and ran 2-week small projects (Project-Based Learning) (Yang, 2021a) (Figure 1). Instead of learning in an indoor laboratory with a risk of coronavirus infection, students learn outdoors on the university campus, so-called the living laboratory (Lindstrom and Middlecamp, 2017). With some supervision, students proposed some projects on air pollution on campus. After reading some references, students developed project plans with detailed fieldwork and air quality measurements using the Flow 2 air quality sensor. With some guidance and demonstration from the supervisor, students carried out fieldwork and collected air quality data on campus using Flow 2 sensors (Figure 2). On the basis of the group data, each team delivered a group presentation, and all students completed their individual essays.

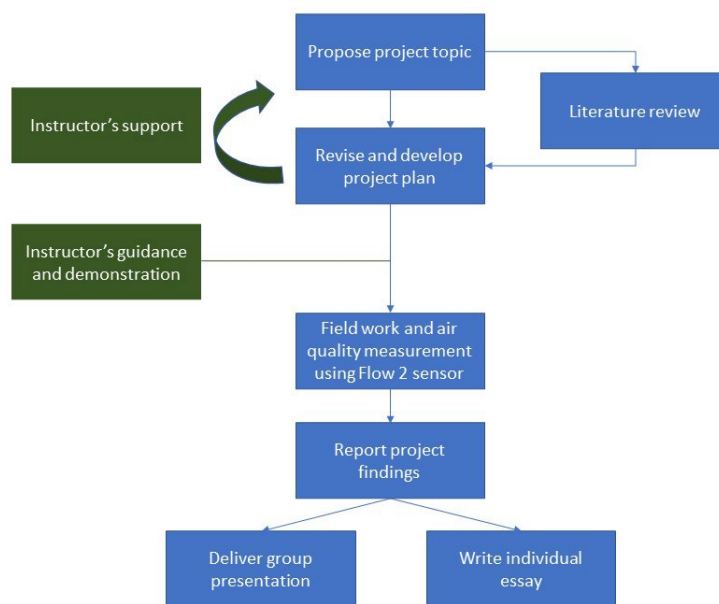


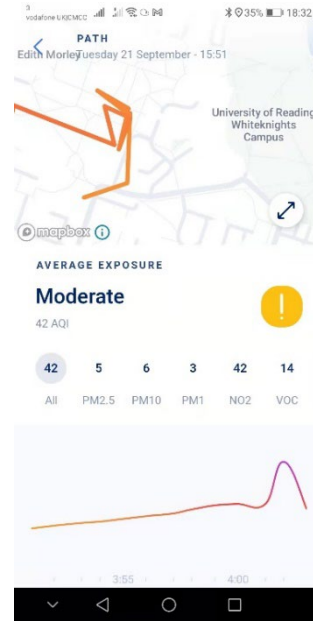
Figure 1: Pedagogic design of students’ blended learning using low-cost sensors during the COVID-19 pandemic

2.2 Analysing students’ learning experiences

To understand the learners’ perception of the low-cost sensors and to evaluate the effectiveness of learning using the sensors, this research adopted both quantitative and qualitative methods for data collection. The online questionnaire (quantitative data) was conducted at the end of the module. The questions include students’ opinions on learning methods, relevance to the real world, developing abilities as an independent learner, helping students to learn, creating a sense of belonging, providing adequate opportunities to interact with other students, and overall satisfaction. A total of ten students were interviewed separately for their feedback on teaching and learning (text, qualitative data). The descriptive statistics were conducted for the survey data (Loeb et al., 2017), and the thematic analysis method was used to analyse the qualitative data (Braun and Clarke, 2012).



(A)



(B)

Figure 2: The low-cost air quality Flow 2 sensor was used in blended learning (A). The Flow App can directly show the air quality data and walking path (GPS location) on the phone, and the air quality data can be downloaded for learning (B)

3. Results

3.1 Quantitative data results

Figure 3 illustrates the questionnaire results for students’ perception of learning using low-cost sensors. Around 93% of the 27 students confirmed having a positive learning experience using a range of teaching methods, particularly low-cost air quality sensors. Because students can measure air quality by themselves, the majority of the students thought their learning was relevant to the real world. Most students also confirmed that the new teaching method helped to “develop abilities as an independent learner” and “help(ed) student to learn”. During the COVID-19 pandemic, some students suffered from mental health problems (Yang, 2021b). Therefore, it is crucial to create a learning community, where students can study in small teams and help and support each other. Approximately 96% of the students agreed that this module had created a sense of belonging. The majority also confirmed that the module provided adequate opportunities for interaction. Overall, more than 90% of the students were satisfied with the entire module.

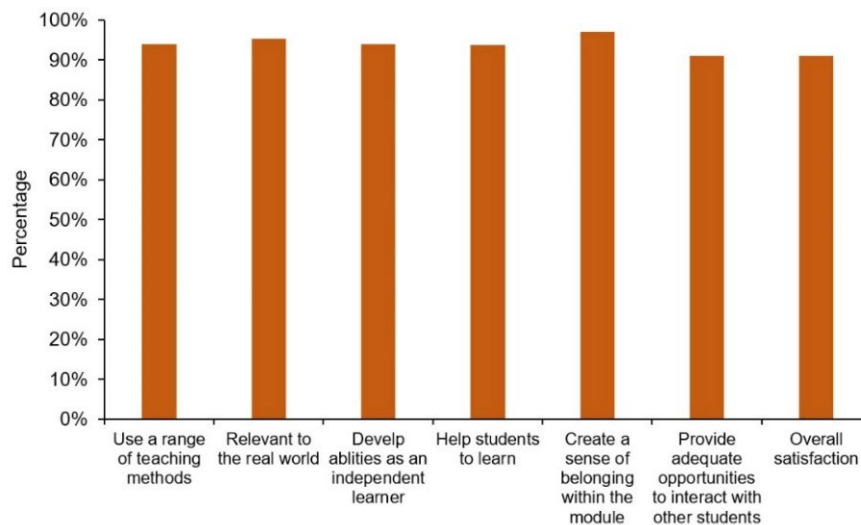


Figure 3: Students’ perception (percentage) of learning using low-cost sensors during the Covid-19 pandemic

3.2 Qualitative data results

To make qualitative results more visible, two word clouds were created for two questions about the learning experience of using low-cost sensors (Figure 4) and team-based learning (Figure 5), based on the counts of the most used words. In Figure 4, sensor, flow, air, and data were mentioned frequently. In Figure 5, team, group, discuss, help, and data were mentioned frequently.



Figure 4: Word cloud of students' feedback on learning using low-cost sensors during the Covid-19 pandemic. Word cloud is in the shape of a graduation cap



Figure 5: Word cloud of students' feedback on team-based learning during the Covid-19 pandemic. Word cloud is in the shape of five hands, indicating learning together within the team

The thematic analysis identified three main themes from the qualitative data.

3.2.1 Students enjoyed learning using low-cost sensors

Similarly, learning using low-cost air quality sensors has received positive feedback from most studies, as emphasised by one student:

“The ability to use the air quality sensors to take our own data around campus is definitely a highlight.”

The sensors are new to all students. At the beginning, some students may worry about the difficulty of using them. However, after the demonstration, students started to like using it to learn air pollution. One student described his/her exciting experience as follows:

“On first consideration, I had preconceptions that they’d be high-tech and hard to control and use, and I had no clue how we were going to be measuring the data. When we were first introduced to them, all of my worries disappeared. They were so simple to figure out and had the most useful App on the phone to connect to and find all the data, and there were never really any problems with the collection.”

3.2.2 Learning using low-cost sensors improves students’ professional skills and employability

For the Environmental Science/Engineering programme, it is crucial to equip students with practical skills through field and laboratory teaching (Davies, 2008). Despite the restrictions imposed by the COVID-19 lockdown and social distancing, the low-cost Flow 2 sensors can directly measure air quality, avoiding the risk of virus infection when studying in the indoor laboratory. Learning in the living laboratory, the university campus outdoors, students obtained practical skills, particularly, using sensors, that improved their employability. For example, one student explained:

“This project has also allowed me to increase my knowledge of using different equipment for needs, specifically air quality sensors. This is an important skill to learn as in my professional career, (as) I may need to use this type of data collection.”

3.2.3 Team-based learning using low-cost sensors creates a learning community

COVID-19 has seriously impacted many students, for example, the mental health problem during online learning, but learning using low-cost sensors in small groups has brought some positive changes to students’ lives. One student exemplified this as follows:

“I believe working as a team for this project has had positive effects on both my studies and everyday life. Working as a team has given me the opportunity to collect and work with large amounts of data which I wouldn't have been able to collect if I was working alone. Working as a group has positively impacted my daily life as it has given me an opportunity to make new friends with similar interests which has been a challenging part of university so far due to COVID-19.”

Another student shared an enjoyable personal experience:

“I enjoyed working with my teammates and learnt new things from them as well. I also met new people.”

4. Discussion

The different types, models and teaching efficiencies of online and blended education have been researched in the last decade, particularly an increasing number of studies since the COVID-19 pandemic (Megahed and Hassan, 2022; Mulenga and Marbán, 2020; Murphy, 2020; Rose, 2020). In general, it is easier for theoretical subjects to transition to e-learning, but it is more challenging for other subjects with more laboratory and practical lessons (Krishnamurthy, 2020). Before the pandemic, online and hybrid education was rarely widely applied in Environmental Science/Engineering teaching, because of the strong tradition of field and laboratory teaching with hands-on experience. In a short period of time, the lockdown and partial lifting of lockdown later pushed the universities to conduct total online learning and blended learning afterwards. University staff had to deliver the new form of teaching with limited formal training. Importantly, new technologies and delivery modes need to align with study aims and produce a learning environment where students are able to build their own knowledge with hands-on experience (Megahed, 2014; Saghafi and Crowther, 2021). With the rapid development of ICT, integrating new technologies, such as portable sensors, can provide students the chance to engage in active learning and absorb the taught knowledge, based on their own practice (Chen and You, 2010; Crowther, 2013).

According to the technology integration matrix (TIM) (Jonassen et al., 2003), five technological integration levels (entry, adoption, adaptation, infusion and transformation) and corresponding five different study characteristics (active, collaborative, constructive, authentic and goal-directed) appear in the study process. The burgeoning of blended learning during the COVID-19 pandemic has already adopted, adapted, and infused

various digital tools, such as MS Teams and portable sensors in this study, in the continuum of teaching and study (Figure 6).

In the last two decades, technology, pedagogy and content knowledge (TPACK) model and a gradual release of responsibility (GRR) model have been increasingly applied in teaching (Figure 6). The TPACK model introduces the interaction among technology, pedagogy and content knowledge, and provides a framework to better facilitate the three basic components (Eutsler, 2022; Koehler and Mishra, 2005; Saudelli and Ciampa, 2016). The GRR model, with appropriate teaching and support, provides a scaffold of student learning responsibility and helps students develop to be an independent learner and explorer, thorough demonstration (instructor does and students watch), shared demonstration (instructor and students do together), guided practice (students do it and instructor watches/guides) and independent practice (Students do it alone) (Fisher and Frey, 2013; Miller, 2002).

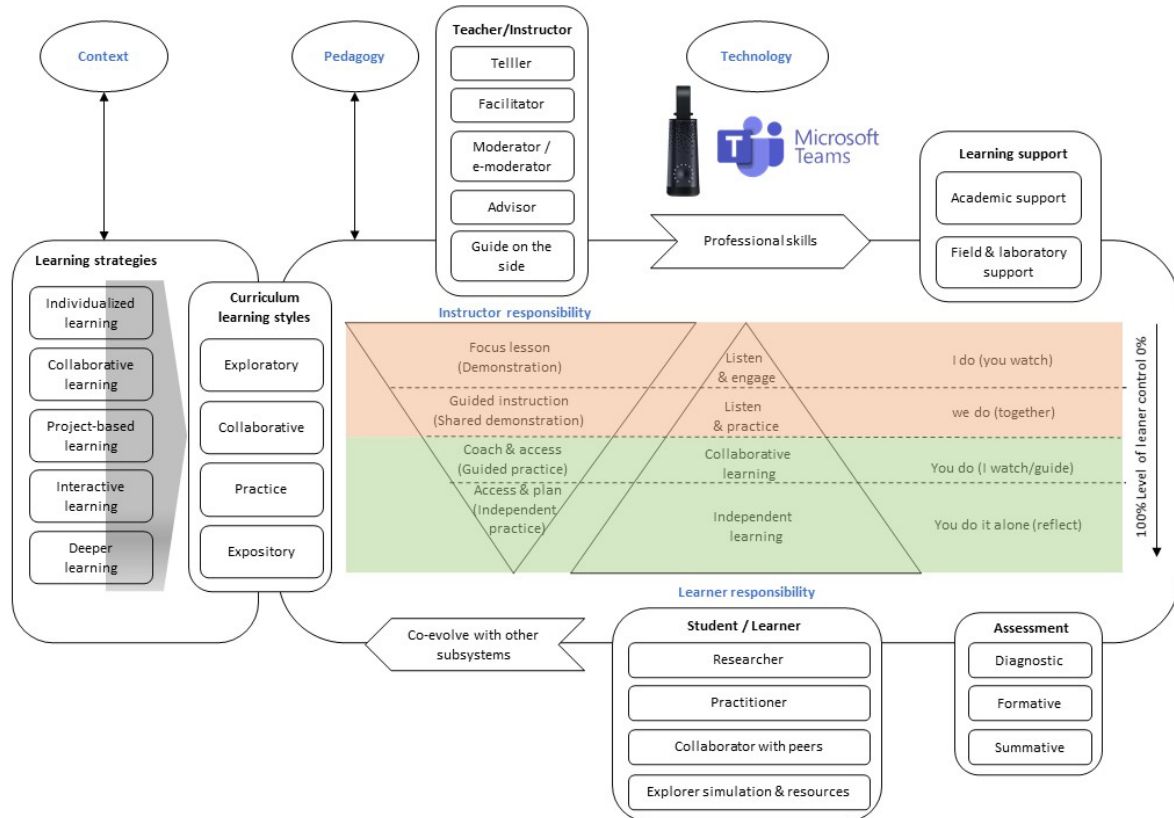


Figure 6: Low-cost sensors used in blended learning based on the technology, pedagogy and content knowledge (TPACK) model and the gradual release of responsibility (GRR) model (adopted from (Botha and Herselman, 2015; Eutsler, 2022; Fisher and Frey, 2013; Koehler and Mishra, 2005; Megahed and Hassan, 2022; Saudelli and Ciampa, 2016))

This research applied the TPACK model, integrating the new technology (portable low-cost sensors) into the pedagogy and content knowledge. Students used the sensors, without access to laboratory during the pandemic, to measure different kinds of air pollutants and practice their skills and explore new local knowledge on air quality. The survey and interviews confirmed the positive feedback on learning using low-cost sensors from students (Figures 3 and 4).

To train students to become independent learners, the GRR model was applied in this research. Firstly, the instructor demonstrated how to use the sensors to measure air quality, while students mainly listened and watched. Secondly, the instructor and students used the sensors together, creating an environment where students can participate along with listening and watching. Thirdly, students used sensors with the instructor’s guidance and watching. Lastly, students applied sensors alone, providing an independent learning and reflection process. The survey data showed more than 90% of the students thought that their learning using low-cost sensors “develops abilities as an independent learner” (Figure 3).

Field and laboratory learning makes an enormous contribution to the development of students' professional skills and indispensable life skills, such as communication and teamwork skills. Irrespective of any measures adopted, universities need to maintain high academic standards and provide good learning experience required for delivering learning outcomes. For situation without access to low-cost sensors, it is still important to produce virtual field and laboratory learning experiences that incorporate photos/results from the field and equipment in the laboratory (Endean and Braithwaite, 2012). Unfortunately, some graduates may suffer from little laboratory practice and skills in the COVID-19 pandemic, probably a long-term, even life-long, disadvantage (Daniel, 2020). Some training, for example, vocational education, is needed for this cohort of students.

This research offers several implications for pedagogic practices and research. Firstly, the successful application of low-cost sensors in the author's teaching sheds light on the appealing potential of expanding the application of low-cost sensors in Environmental Science/Engineering and other teaching programmes, such as Biology, Geography, and Ecology. In the post-COVID-19 era, students will gradually return to laboratories, with access to large and advanced equipment. However, low-cost sensors can still significantly supplement traditional laboratory education. In situations of equipment failure or unavailability of expensive equipment due to various reasons - for example, financial constraints - low-cost sensors can still play an essential role in increasing students' practical skills after the pandemic. Undisputedly, low-cost sensors have some limitations, compared to the advanced and complicated equipment. All low-cost sensors, including the Flow 2 used in the current study, are subject to possible data bias (Giordano et al., 2021). Therefore, regular calibration of these sensors, along with using other equipment, is needed to improve data accuracy. Secondly, in addition to purchasing the sensors from the market, students can also assemble such sensors using different kinds of modules and boards, with supervision from teachers, in a process called the Educational Hardware Hackathon (Richard et al., 2015). Thirdly, it is still unknown when COVID-19 will completely end in the world and what other crisis pedagogy we may encounter in the future, so universities need to learn from the ongoing COVID-19 pandemic and better prepare for the next one. The current study focused on the application of low-cost sensors in the environmental science/engineering programme education at one university. Future studies can further explore the application of low-cost sensors in different subjects at multiple universities in various countries. Studies with a larger scope can enhance our understanding of the contribution of low-cost sensors to students' learning.

5. Conclusion

The Covid-19 pandemic has forced universities to employ e-learning and blended learning, with the consequence of accelerating their development in the last two years. Notably, students' practical skills have been little developed by the online learning alone. In this study, the application of low-cost sensors, without access to laboratories and large equipment, has brought some opportunities to develop students' hands-on experience and improve their professional skills and employability. Learning in small groups also creates a learning community, which is crucial in developing students' teamwork and communication skills and improving mental health during the pandemic. Blending learning will likely become the new normal in the post COVID-19 era and reshape the future of education. These findings have important implications for developing students' practical skills, not only for Environmental Science/Engineering students, but also for other programme students (e.g., Biology, Ecology, Medicine and Geography) in blended learning.

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References

- Botha, A., and Herselman, M. (2015). "A Teacher Tablet Toolkit to meet the challenges posed by 21st century rural teaching and learning environments." *South African Journal of Education*, Vol 35, No. 4, pp 1-19.
- Braun, V., and Clarke, V. (2012). *Thematic analysis*, in Cooper, H., Camic, P., M, Long, D., L, Panter, A., T, Rindskopf, D., and Sher, K., J., (eds.) *APA Handbook of Research Methods in Psychology, Vol 2: Research Designs: Quantitative, Qualitative, Neuropsychological, and Biological*, American Psychological Association, Washington, DC, pp. 57-71.
- Chan, K. S., Schillereff, D. N., Baas, A. C. W., Chadwick, M. A., Main, B., Mulligan, M., O'Shea, F. T., Pearce, R., Smith, T. E. L., van Soesbergen, A., Tebbs, E., and Thompson, J. (2021). "Low-cost electronic sensors for environmental research: Pitfalls and opportunities." *Progress in Physical Geography*, Vol 45, No. 3, pp 305-338.
- Chen, W. Z., and You, M. L. (2010). "Student response to an Internet-mediated industrial design studio course." *International Journal of Technology and Design Education*, Vol 20, No. 2, pp 151-174.

- Crowther, P. (2013). "Understanding the signature pedagogy of the design studio and the opportunities for its technological enhancement." *Journal of Learning Design*, Vol 6, No. 3, pp 18-28.
- Daniel, S. J. (2020). "Education and the COVID-19 pandemic." *Prospects*, Vol 49, No. 1, pp 91-96.
- Davies, C. (2008). *Laboratory and Practical Work in the Engineering Curriculum. Learning and Teaching in Laboratories*, The Higher Educational Academy Engineering, Heslington, UK.
- Dhawan, S. (2020). "Online learning: A panacea in the time of COVID-19 crisis." *Journal of Educational Technology Systems*, Vol 49, No. 1, pp 5-22.
- Endean, M., and Braithwaite, N. (2012). "Online Practical Work for Science and Engineering Students - A Collaborative Scoping Activity between the UK Open University and East China University of Science and Technology", [online], <http://www.open.ac.uk/about/teaching-and-learning/esteem/sites/www.open.ac.uk/about/teaching-and-learning/esteem/files/files/ecms/web-content/2012-08-Mark-Endean-final-report.pdf>.
- Eutsler, L. (2022). "TPACK's pedagogy and the gradual release of responsibility model coalesce: integrating technology into literacy teacher preparation." *Journal of Research on Technology in Education*, Vol 54, No. 3, pp 327-344.
- Fisher, D., and Frey, N. (2013). *Better learning through structured teaching: A framework for the gradual release of responsibility*, Association for Supervision & Curriculum Development, Alexandria, VA.
- Gamage, K. A. A., Wijesuriya, D. I., Ekanayake, S. Y., Rennie, A. E. W., Lambert, C. G., and Gunawardhana, N. (2020). "Online delivery of teaching and laboratory practices: continuity of university programmes during COVID-19 pandemic." *Education Sciences*, Vol 10, No. 10, pp 291.
- Giordano, M. R., Malings, C., Pandis, S. N., Presto, A. A., McNeill, V. F., Westervelt, D. M., Beekmann, M., and Subramanian, R. (2021). "From low-cost sensors to high-quality data: A summary of challenges and best practices for effectively calibrating low-cost particulate matter mass sensors." *Journal of Aerosol Science*, Vol 158, No., pp 1-23.
- Horsburgh, J. S., Caraballo, J., Ramirez, M., Aufdenkampe, A. K., Arscott, D. B., and Damiano, S. G. (2019). "Low-Cost, Open-Source, and Low-Power: But What to Do With the Data?" *Frontiers in Earth Science*, Vol 7, No., pp 1-14.
- Jonassen, D. H., Howland, J., Moore, J., and Marra, R., M. (2003). *Learning to solve problems with technology: A constructivist perspective*, Merrill Prentice Hall, Upper Saddle River, NJ.
- Kapilan, N., Vidhya, P., and Gao, X.-Z. (2021). "Virtual laboratory: A boon to the mechanical engineering education during Covid-19 pandemic." *Higher Education for the Future*, Vol 8, No. 1, pp 31-46.
- Khanal, R. (2021). "Crisis Pedagogy: Student Perceptions of Pedagogical Transition amidst the COVID-19." *Pedagogical Research*, Vol 6, No. 2, pp em0094.
- Koehler, M. J., and Mishra, P. (2005). "Teachers learning technology by design." *Journal of computing in teacher education*, Vol 21, No. 3, pp 94-102.
- Krishnamurthy, S. (2020). "The future of business education: A commentary in the shadow of the Covid-19 pandemic." *Journal of Business Research*, Vol 117, No., pp 1-5.
- Lewis, D. I. (2014). *The pedagogical benefits and pitfalls of virtual tools for teaching and learning laboratory practices in the biological sciences*, The Higher Education Academy, Heslington, UK.
- Lindstrom, T., and Middlecamp, C. (2017). "Campus as a Living Laboratory for Sustainability: The Chemistry Connection." *Journal of Chemical Education*, Vol 94, No. 8, pp 1036-1042.
- Loeb, S., Dynarski, S., McFarland, D., Morris, P., Reardon, S., and Reber, S. (2017). *Descriptive Analysis in Education: A Guide for Researchers (NCEE 2017-4023)*, U.S. Department of Education, Institute of Education Sciences, National Center for Education Evaluation and Regional Assistance, Washington, DC.
- Megahed, N., and Hassan, A. (2022). "A blended learning strategy: reimagining the post-Covid-19 architectural education." *Archnet-Ijar International Journal of Architectural Research*, Vol 16, No. 1, pp 184-202.
- Megahed, N. A. (2014). "Augmented Reality based-learning assistant for architectural education." *International Journal on Advances in Education Research*, Vol 1, No. 1, pp 35-50.
- Michaelsen, L., K., Parmelee, D., X, Hyderi, A., and Sweet, M. (2011). *Team-Based Learning: overview and best evidence*, in Brown, T. and Williams, B., (eds.) *Evidence-Based Education in the Health Professions*, CRC Press, London, UK, pp. 313-329.
- Miller, D. (2002). *Reading with meaning: Teaching comprehension in the primary grades*, Stenhouse Publishers, Portsmouth, NH.
- Mulenga, E. M., and Marbán, J. M. (2020). "Prospective teachers' online learning mathematics activities in the age of COVID-19: A cluster analysis approach." *Eurasia Journal of Mathematics, Science and Technology Education*, Vol 16, No. 9, pp 1305-8215.
- Murphy, M. P. A. (2020). "COVID-19 and emergency eLearning: Consequences of the securitization of higher education for post-pandemic pedagogy." *Contemporary Security Policy*, Vol 41, No. 3, pp 492-505.
- Nel, C., and Marais, E. (2020). "Preservice Teachers Use of WhatsApp to Explain Subject Content to School Children during the COVID-19 Pandemic." *International Journal of Work-Integrated Learning*, Vol 21, No. 5, pp 629-641.
- QAA. (2020). "COVID-19: Thematic Guidance-Practice and Lab-Based Assessment", [online], https://www.qaa.ac.uk/docs/qaa/guidance/covid-19-thematic-guidance-work-based-learning.pdf?sfvrsn=e3cecd81_8.
- Richard, G. T., Kafai, Y. B., Adleberg, B., and Telhan, O. "StitchFest: Diversifying a College Hackathon to broaden participation and perceptions in computing." *Presented at SIGCSE '15: The 46th ACM Technical Symposium on Computer Science Education*, Kansas City, MO, USA.

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- Rose, S. (2020). "Medical Student Education in the Time of COVID-19." *Journal of the American Medical Association*, Vol 323, No. 21, pp 2131-2132.
- Saghafi, M. R., and Crowther, P. (2021). "Integrating technology subjects with design studio teaching: comparing curriculum of architecture education in Australia and Iran." *Archnet-Ijar International Journal of Architectural Research*, Vol 15, No. 3, pp 652-667.
- Saudelli, M. G., and Ciampa, K. (2016). "Exploring the role of TPACK and teacher self-efficacy: an ethnographic case study of three iPad language arts classes." *Technology Pedagogy and Education*, Vol 25, No. 2, pp 227-247.
- Teixeira, D., Maron, M., and van Rensburg, B. J. (2019). "Bioacoustic monitoring of animal vocal behavior for conservation." *Conservation Science and Practice*, Vol 1, No. 8, pp e72.
- Teräs, M., Suoranta, J., Teräs, H., and Curcher, M. (2020). "Post-Covid-19 education and education technology 'solutionism': A seller's market." *Postdigital Science and Education*, Vol 2, No. 3, pp 863-878.
- Yang, H. (2021a). *Application of project based learning in an environmental engineering programme*, in Guerra, A., Chen, J., Winther, M., Kolmos, A., and Nielsen, S. R., (eds.) *Educate for the future: PBL, Sustainability and Digitalisation 2021*, Aalborg University, Aalborg, Denmark, pp. 195-205.
- Yang, H. (2021b). *Environmental Engineering undergraduate dissertation work during the Covid-19 pandemic*, in Heiß, H.-U., Järvinen, H.-M., Mayer, A., and Schulz, A., (eds.) *European Society for Engineering Education (SEFI) 49th Annual Conference: Blended Learning in Engineering Education: Challenging, Enlightening - and Lasting?*, Technische Universität Berlin, Berlin, pp. 1337-1345.