International Journal of Modern Education (IJMOE)
Journal Website: http://ijmoe.com/
eISSN: 2637-0905

ASPERLABS: OPEN SOURCE VIRTUAL LABORATORIES FOR STEM EDUCATION

Muhammad Alif Mohammad Latif[1*], Mohd Ezad Hafidz Hafidzuddin[2], Marina Mohd Top@Mohd Tah[3], Norihan Md Arifin[4]

[1] Centre of Foundation Studies for Agricultural Science, Universiti Putra Malaysia, Malaysia
Email: aliflatif@upm.edu.my
[2] Centre of Foundation Studies for Agricultural Science, Universiti Putra Malaysia, Malaysia
Email: ezadhafidz@upm.edu.my
[3] Centre of Foundation Studies for Agricultural Science, Universiti Putra Malaysia, Malaysia
Email: marinamohd@upm.edu.my
[4] Centre of Foundation Studies for Agricultural Science, Universiti Putra Malaysia, Malaysia
Email: norihana@upm.edu.my
[*] Corresponding Author

Article Info:

Article history:
Received date: 31.05.2020
Revised date: 10.06.2020
Accepted date: 14.06.2020
Published date: 15.06.2020

To cite this document:

Latif, M. A. M., Hafidzuddin, M. E. H., Mohd Tah, M. M. T., & Arifin, N. M. (2020). Asperlabs: Open Source Virtual Laboratories for STEM Education. International Journal of Modern Education, 2(5), 29-37.

DOI: 10.35631/IJMOE.25004

Abstract:

The main challenge in the development of scientific education in Malaysia is the lack of interest in science among students. One of the reasons for this discrepancy lies in the fact that these fields often require laboratory exercises to provide effective skill acquisition and hands-on experience. Physical experiments increase the costs due to their required equipment, space, and maintenance staff. A virtual laboratory can provide a cost-efficient way to organize high-quality laboratory work for many students. It is a damage resistance laboratory, thus opening the possibility to learn from mistakes. In Science, Technology, Engineering, and Mathematics (STEM) education, virtual laboratories can offer effective scientific exploration at a low cost. The objective of this research is to develop a platform for open-source virtual laboratories for STEM education inside and outside of Universiti Putra Malaysia (UPM). The virtual laboratory initiative is known as "AsperLabs". This web-based interface offers several open-source virtual experiments for three subjects including physics, chemistry, and biology. Asperlabs have been utilized at Foundation level in UPM and STEM programs at local secondary schools. It has received positive feedback from students on both levels and will be included in the course materials for Foundation Program at UPM in the near future.

Keywords:

Virtual Laboratory, STEM Education, Virtual Experiments

Copyright © GLOBAL ACADEMIC EXCELLENCE (M) SDN BHD - All rights reserved

Introduction

Science education needs laboratory exercises as part of the skill acquisition process. In university, hands-on laboratory works are needed to achieve the process. However, due to the budget and time constraints, only selected laboratory works are used. Two different viewpoints to the resolution have appeared. One is developing a physical (real) laboratory with distance access (remote laboratory), while the other means developing a fully software-based virtual laboratory (VL). The first option, of a remote-access physical laboratory, although possible to create, can be prohibitively complex, especially regarding the communication and sensory-control hardware and software required, and the overall expense of the equipment and maintenance. Also, it is a relatively inefficient solution with poor scalability (only one student can access a workplace at a time), and it does not easily support more complex collaborative learning scenarios. The fully software based VL can avoid some of these drawbacks. It has been widely accepted that VL systems and simulators are the desired initial step in science education and training while recognizing that more advanced learners will still need hands-on experience with real equipment. However, with the rapid progress in computer graphics, virtual reality, and virtual worlds technologies the boundary between what can only be done in the real world and what can be done in the virtual world is reducing.

Physical labs increase the costs due to their required equipment, space, and maintenance staff. Furthermore, they have additional disadvantages such as being unable to support distance learning, issue related to laboratory accessibility to handicapped people, and safety issue for dangerous experimentation. During economic depressions, many laboratory equipment and material cannot be procured due to budget constraint. For a very large number of students such as in Pusat Asasi Sains Pertanian (PASP) UPM, physical laboratory experiments can become very costly and time-consuming. VLs is the desired initial step in science and technology education nowadays. VLs can provide a cost-efficient way for the university to organize high-quality laboratory work for many students such as at PASP UPM, without having them to share the same equipment. VL works are also damage-resistance, thus opening the possibility to learn from mistakes. By combining with the learning management system (LMS), assessing student performance in laboratory works becomes much easier. The objective of this research is to develop an open-source VL platform for science education at the pre-university level, Foundation Program in UPM.

Literature Review

The term STEM, which is an acronym for Science, Technology, Engineering and Mathematics, originated at the National Science Foundation (NSF) in the 1990s. Since then, STEM has been widely used as a generic label for any activity or program that involves one or several of the STEM disciplines (Bybee 2010; Ostler 2012). Engaging students in high-quality STEM education is a big challenge. According to Kennedy & Odell (2014), it requires programs to include rigorous curriculum, instruction, and assessment, integrate technology and engineering into the science and mathematics curriculum and promote scientific inquiry and the engineering design process. All of these are achievable with help from computers and online technologies. The spread of online technologies has been widely analysed at the faculty level, as for example in San Francisco State University (SFSU), where 70% of all courses use online technologies (Beatty & Ulasewicz, 2006). Easy Java Simulations (EJS) (Christian and Esquembre, 2007) is a tool specifically created for designing and developing interactive VLs; that is, the simulation and the graphical user interface. Moreover, EJS not only has been successfully used and improved by many research groups to create VLs but also to create the Graphical User Interfaces (GUIs) of their remote counterparts (Heradio *et al*., 2011).

Copyright © GLOBAL ACADEMIC EXCELLENCE (M) SDN BHD - All rights reserved

Digital game-based learning and computer simulations have been found to be effective in STEM classrooms. Digital game-based learning can facilitate learning in a technology-enhanced environment and has been proven to increase student's motivation in STEM (Gee, 2007; Kiili, 2007; Prensky, 2001). On the other hand, computer simulations are tools that model a real-world phenomenon by performing calculations based on a theoretical principle. Example of computer simulations that can be used in STEM education are visualizations, animations and VLs (Smetana & Bell, 2012). Computer simulations can promote active engagement in high order thinking and via problem-solving (Hargrave & Kenton, 2000). They can also enable visualization of time-consuming and hazardous phenomena which are difficult to explain in the classroom or laboratory (van Joolingen *et al*., 2007). However, computer simulations such as VLs are supposed to be used to complement, not replace, other pedagogical practices (Smetana & Bell, 2012). Furthermore, students also need to be guided to interact with this tool.

Contrary to traditional laboratories, VLs are known to reduce cost and simplify maintenance of laboratory facilities, while offering students a safe environment to build up experience and enthusiasm for STEM. Furthermore, they enable students to interact in inquiry-based classes where they can implement and analyse their own experiments, learn by using virtual objects and apparatus (Lynch & Ghergulescu, 2017). Other advantages of VLs include: develop reasoning, critical thinking, innovative and creative skills without the usual limitations of time, resources and space (Wang et al., 2015); enable inquiry-based learning while assisting in the acquisition of deep conceptual domain knowledge and inquiry skills (Jong et al., 2014); allow resources to be shared between geographically distributed educational institutions and users (Wolf, 2010); simulating dangerous or impossible-to-carry-out experiments (Chen et al., 2010); and lastly, providing chances to change the parameters and redo the experiment countless times (Chen et al., 2010). The review for existing VLs has been done extensively in the paper written by Lynch & Ghergulescu (2017).

Methods

The initiative is carried out in three phases. Firstly, the criteria for each VL were determined based on the availability as open-source and the suitability with the syllabus for UPM Foundation Program. The experiments selected for the VLs are the same conducted in the physical laboratory so that the correlation between the virtual and physical experiment can be established. The second phase involved designing and building the website, AsperLabs to host all selected VLs. Pilot testing was carried out in order to validate the protocols/instructions designed for each of the modules. Lastly, AsperLabs was deployed for public use. For the UPM Foundation Program students, the VL activities were carried out during the course of the semester. Assessment on the impact of virtual laboratory to the students were conducted in the form of questionnaire. For the UPM Foundation Program students, the virtual laboratories were assessed in terms of helping the students to increase their understanding of the subject matter and prepare for actual laboratory activities. Meanwhile, for the assessment of students outside UPM, the questions were focused on the use of virtual experiments in STEM activities.

Development of AsperLabs

AsperLabs web interface was designed and built using WordPress and the open-source VLs were identified. The website to host the VLs was built and temporarily located at http://asperlabs.tcchem.blog. The fully functioning AsperLabs will be hosted inside UPM using the domain www.asperlabs.upm.edu.my. The web interface offers four subjects to choose from, Physics, Chemistry, Biology and Mathematics.

Copyright © GLOBAL ACADEMIC EXCELLENCE (M) SDN BHD - All rights reserved

Physics Modules

The physics modules contained two experiments, Projectile Motion and Circuit Construction. Both VLs were developed by the PhET Project (Wieman and Perkins, 2006). In the Projectile Motion experiment (Figure 1), students were allowed to shoot a variety of objects such as a pumpkin, cannonball, golf ball, football and many more from an adjustable height and distance. This module allows students to explore the concept of projectile and ballistics. The experiment will show that the mass of the object does not contribute to the projectile as long as it has the same initial velocity. In UPM Foundation Program, the students learned about projectile motion in the second chapter of subject *Physics I* and performed the corresponding physical experiment in the laboratory. Meanwhile, the Circuit Construction module is used to let students design and test different electrical circuit setups according to the instructions given.

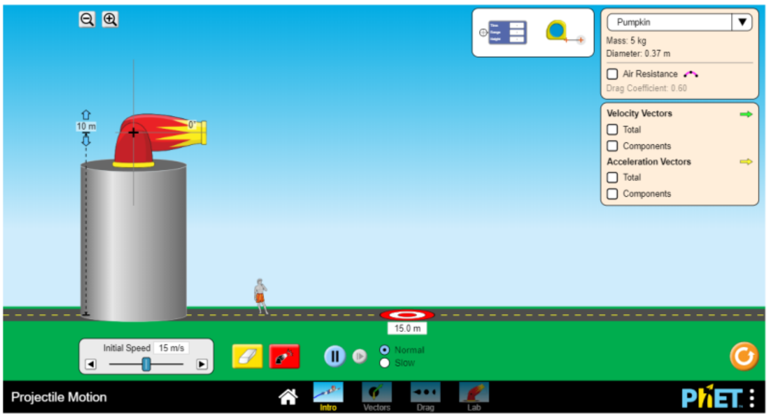

Figure 1: Screenshot of the Projectile Motion Experiment
Source: PhET Interactive Simulations, University of Colorado Boulder (https://phet.colorado.edu)

Chemistry Modules

The chemistry modules contained two experiments, Acid-Base Titration (developed by ChemCollective, Yaron *et al.*, 2010) and Valence Shell Electron Pair Repulsion (VSEPR) theory (developed by PhET Project, Wieman and Perkins, 2006). In the Acid-Base Titration module (Figure 2), students will perform a virtual titration of sodium hydroxide (NaOH), a strong base with hydrochloric acid (HCl), a strong acid. This will result in the formation of a neutral salt, sodium chloride (NaCl). Detailed instruction is given to the students. This instruction is exactly the procedure required to perform the titration in a physical lab. The UPM Foundation Program students learned about the acid-base theory in the third chapter of the subject *Chemistry II* and perform the same experiment in the laboratory. Students will perform the virtual titration and plot a titration curve. This plot will be compared with the ones obtained from the physical experiment. The VSEPR module will help students increase their understanding of the theory and is applied during class. This theory is covered in chapter 11 of the subject *Chemistry I* for the UPM Foundation Program.

Biology Modules

For biology, two activity modules were included. These are Thermodynamics in Cell Biology and 3D DNA Structure Manipulation. The cell thermodynamics activity is developed at the University of Wisconsin-Madison under the project "*Connecting Concepts: Interactive Lessons in Biology*" (https://ats.doit.wisc.edu/biology/about.htm). In this activity, students are required to ensure the survival and manage the reproduction of a paramecium by moderating energy consumption. The 3D DNA Structure Manipulation module is using open-source software called Jmol (Cass *et al.*, 2005). The experiment allows students to view the atomic

Copyright © GLOBAL ACADEMIC EXCELLENCE (M) SDN BHD - All rights reserved

structure of a protein-DNA complex (the lambda repressor-operator complex) and manipulate the structural representation of the protein and the DNA.

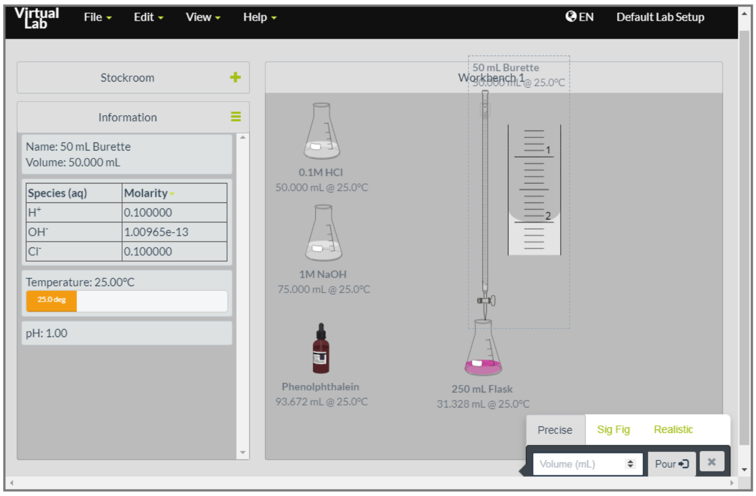

Figure 2: Screenshot of the Acid-Base Titration Experiment

Source: Chemistry Collective (http://chemcollective.org/)

Results and Discussion

Deployment and Testing at PASP UPM

AsperLabs were integrated into the *Physics I* for projectile motion experiment and *Chemistry I* courses for the acid-base titration experiment. Students were instructed to perform the virtual experiment prior to the practical session. For acid-base titration experiment, students already had a concentration versus pH plot (results from the virtual experiment) as a pre-laboratory requirement. After performing the titration, students will compare the results and perform self-reflection on the successfulness of their physical experiment. A sample of one class (45 students) was used to evaluate the effectiveness of the physics (Projectile Motion) (Figure 3a) and chemistry (Acid-Base Titration) (Figure 3b) virtual experiments.

Figure 3: a(left) Performing the Projectile Motion Experiment and b(right) Comparing Data from the Acid-Base Titration Virtual Experiment

Copyright © GLOBAL ACADEMIC EXCELLENCE (M) SDN BHD - All rights reserved

International Journal of Modern Education (IJMOE)
Volume 2 Issue 5 (June 2020) PP. 29-37
DOI: 10.35631/IJMOE.25004

Table 1: Student Feedbacks on the use of Virtual Experiments

	Q1	Q2	Q3
Strongly Agree	55.6%	66.7%	53.3%
Agree	31.1%	26.7%	37.8%
Slightly Disagree	13.3%	4.4%	8.9%
Disagree	0.0%	2.2%	0.0%

Q1: The virtual experiment was easy to do and the instructions were clear; Q2: The virtual experiment helped me prepare for the actual experiment; Q3: Virtual laboratories can help me increase my understanding of the subject matter.

Table 1 shows that 86.7% of the students agreed that the virtual experiments were easy to carry out and the instructions were adequate to conduct the experiments. Almost all (93.4%) students felt that the virtual experiments helped them to prepare for the actual physical experiments. Overall, 91.1% of the students agreed that virtual experiments can help them to improve their understanding of the subject matter. Overall, the virtual experiments received positive feedback from the students. For the Projectile Motion experiment, students were able to apply the concept taken from the virtual experiment to the physical one. More than half of the students were able to hypothesize the outcome of the physical experiments even before conducting the physical experiment. For the case of Acid-Base Titration experiment, some of the students had difficulties in carrying out the virtual experiment the first time. But they were able to obtain the results after several attempts.

Integration in STEM Program Outside UPM

Since AsperLabs is practically a website, it can be accessed from anywhere with an internet connection. After the successful implementation of VLs for the physics and chemistry subjects, AsperLabs were brought outside UPM to be included in PASP UPM annual STEM program known as Program Pintar Sains dan Matematik (PSM) 2019. This program was organized by PASP UPM and Sekolah Menengah Kebangsaan (SMK) Taman Bunga Raya 1, Rawang, Selangor with the cooperation from the Hulu Selangor district education office. The main objective of the program is to increase the awareness of science towards students in the rural area, with the aim to increase the number of students pursuing science as their educational choice and career path. The program was held on 21st October 2019. A total of 158 students (71 male and 87 female) attended the program, focusing on students taking the Form Three Assessment (PT3) in 2019. Twelve STEM activities were carried out with two of them were VLs. The students were allowed to carry out the Projectile Motion (Figure 4a) from AsperLabs and "Build a Caffeine Molecule" (Figure 4b) virtual experiments.

Figure 4: a(left) Projectile Motion Experiment and b(right) Building 3D Molecule at PSM 2019.

Copyright © GLOBAL ACADEMIC EXCELLENCE (M) SDN BHD - All rights reserved

International Journal of Modern Education (IJMOE)
Volume 2 Issue 5 (June 2020) PP. 29-37
DOI: 10.35631/IJMOE.25004

In general, the program received positive feedback from the students (Figure 5). All students found the virtual experiments interesting, whilst 93% of students agreed that the inclusion of virtual experiments can motivate them into pursuing science and mathematics. 94.3% of the students think that VLs stimulate their thinking in using science and mathematics to solve problems. Overall, more than 98% of the students felt that the program was successful and meaningful.

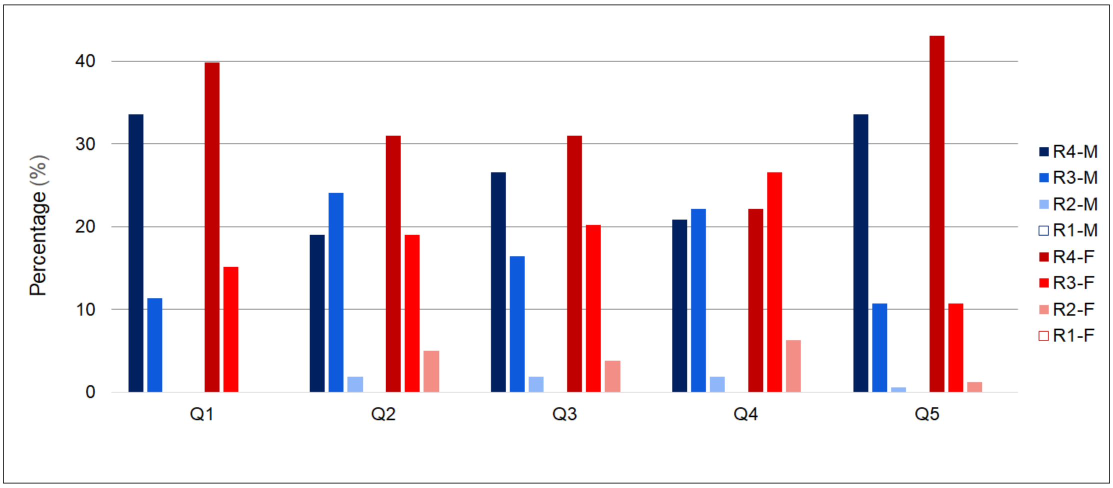

Figure 5: Student Feedback on the Use of VLs in PSM 2019

Q1: Virtual experiment provided in the program is interesting; Q2: The use of virtual laboratory interests me and motivate me towards science and mathematics; Q3: This program stimulates my thinking about the use of science and mathematics in solving problems; Q4: This program increases my appreciation about science and mathematics subjects; Q5: Overall, this program is successful and meaningful; R4-M: Strongly Agree (male); R3-M: Agree (male); R2-M Slightly Disagree (male); R1-M: Disagree (male) R4-F: Strongly Agree (female); R3-F: Agree (female); R2-F Slightly Disagree (female); R1-F: Disagree (female)

The trend in the response from male or female students was similar, except for Q2. This indicates that for the current generation, inclusiveness of technology such as computer simulations in the learning experience is accepted by both genders. In the era of information technology, these simulations are well within reach. However, the main lingering issue seems to be the awareness of alternative learning tools such as VLs. When asked, most of the students were not aware of the availability of computer simulations in teaching and learning. However, this issue can be easily fixed with the help of teachers by exposing the students to STEM education tools like AsperLabs. For most of the students, this was their first time using a computer to solve physics and chemistry problems. Nevertheless, based on observation during the program, they did not show any difficulty of carrying out the experiment.

Conclusion

AsperLabs was successfully deployed as an alternative teaching tool for UPM Foundation Program students. The feedback analysis showed that UPM Foundation Program students were positively affected by the use of VLs activities. This also indicates the readiness of the current generation to apply computer-assisted learning during their study at the university. AsperLabs was also successful in facilitating STEM activities for students in the rural area. Both genders showed similar interests and positive attitude towards the use of computer simulations in STEM education. However, student awareness towards computer simulations in STEM education is still the main issue. This issue can be easily solved by exposing them to alternative learning tools such as AsperLabs since middle school.

Copyright © GLOBAL ACADEMIC EXCELLENCE (M) SDN BHD - All rights reserved

Acknowledgements
The project is supported by Geran Insentif Penyelidikan dalam Pengajaran dan Pembelajaran (GIPP), Universiti Putra Malaysia. GIPP-9323693. The authors would like to acknowledge the funding for STEM activities from Geran Putra, Universiti Putra Malaysia, Vot Number: 9589700.

References
Beatty, B., & Ulasewicz, C. (2006). Faculty perspectives on moving from Blackboard to the Moodle learning management system. *TechTrends*, 50(4), 36-45.

Bybee, R. W. (2010). Advancing STEM Education: A 2020 Vision. *Technology and Engineering Teacher*, 70(1), 30–35.

Cass, M. E., Rzepa, H. S., Rzepa, D. R., & Williams, C. K. (2005). The use of the free, open-source program Jmol to generate an interactive web site to teach molecular symmetry. *Journal of Chemical Education*, 82(11), 1736.

Chen, X., Song, G., & Zhang, Y. (2010). Virtual and Remote Laboratory Development: A Review. *Earth and Space*, 2010, 3843–3853.

Christian, W., & Esquembre, F. (2007). Modelling physics with easy java simulations. *The Physics Teacher*, 45(8), 475-480.

Gee, J. P. (2007). *Good video games+good learning: Collected essays on video games, learning, and literacy*. Peter Lang.

Hargrave, C. P., & Kenton, J. M. (2000). Preinstructional simulations: Implications for science classroom teaching. *Journal of Computers in Mathematics and Science Teaching*, 19(1), 47-58.

Heradio, R., de la Torre, L., Sanchez, J., Dormido, S., & Vargas, H. (2011). An architecture for virtual and remote laboratories to support distance learning. In: *Research in Engineering Education Symposium*. Madrid, Spain.

Jong, T. D., Sotiriou, S., & Gillet, D. (2014). Innovations in STEM education: The Go-Lab federation of online labs. *Smart Learning Environments*, 1(3). 2014.

Kennedy, T. J., & Odell, M. R. L. (2014). Engaging students in STEM education. *Science Education International*, 25(3), 246-258.

Kiili, K. (2007). Foundation for problem-based gaming. *British Journal of Educational Technology*, 38(3), 394-404.

Lynch, T., & Ghergulescu, I. (2017). Review of Virtual Labs as The Emerging Technologies for Teaching Stem Subjects. *INTED2017 Proceedings*, 6082–6091.

Ostler, E. (2012). 21st Century STEM Education: A Tactical Model for Long-Range Success. *International Journal of Applied Science and Technology*, 2(1), 28–33.

Prensky, M. (2001). Fun, play and games: What makes games engaging. *Digital game-based Learning*, 5(1), 5-31.

Smetana, L. K., & Bell, R. L. (2012). Computer simulations to support science instruction and learning: A critical review of the literature. *International Journal of Science Education*, 34(9), 1337-1370.

Van Joolingen, W. R., De Jong, T., & Dimitrakopoulou, A. (2007). Issues in computer-supported inquiry learning in science. *Journal of Computer Assisted Learning*, 23(2), 111-119.

Wang, J., Guo, D., & Jou, M. (2015). A study on the effects of model-based enquiry pedagogy on students' inquiry skills in a virtual physics lab. *Computers in Human Behavior*, 49, 658–669.

Wieman, C. E., & Perkins, K. K. (2006). A powerful tool for teaching science. *Nature Physics*, 2(5), 290-292.

Copyright © GLOBAL ACADEMIC EXCELLENCE (M) SDN BHD - All rights reserved

Wolf, T. (2010). Assessing Student Learning in a Virtual Laboratory Environment. *IEEE Transactions on Education*, 53(2), 216–222.

Yaron, D., Karabinos, M., Lange, D., Greeno, J. G., & Leinhardt, G. (2010). The ChemCollective-virtual labs for introductory chemistry courses. *Science*, 328(5978), 584-585.

Copyright © GLOBAL ACADEMIC EXCELLENCE (M) SDN BHD - All rights reserved