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Review Article

From Traditional Hands-On Laboratories to Virtual Reality Lab Environment: Review on Lab Teaching Technologies to Frost Learning Outcome and Mitigate the Negative Impact of the COVID-19 Pandemic

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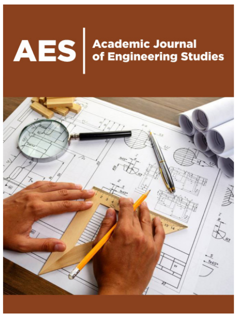

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Abstract

Engineering education cannot be performed without practicing in laboratories, as the prime objective of engineering education is to gear students up for practicing engineering. A traditional teaching laboratory is a place where engineering instructions and hands-on practice take place. However, since the early spring of 2020, the coronavirus COVID-19 outbreak has hindered face-to-face teaching as well as traditional hands-on laboratories. This pandemic forces universities to migrate from the traditional way of education to an online approach. Despite some concerns about the quality of substitutional approaches compared to conventional hands-on Labs, studies show that these types of laborites simulate critical thinking and lead to higher learning outcomes. This work reviews the important role of experimental laboratories in engineering education. It highlights the innovations in lab teaching, and how remote and virtual labs influence engineering education and mitigate the impact of pandemic COVID-19 on higher education outcomes.

Keywords: Traditional labs;Online labs;Virtual labs;Remote labs; COVID-19 influence on learning outcome

Introduction

Engineering curricula aim to supply students with the required competences to face the challenges of the present and future. While engineering is a hands-on profession that utilizes raw materials using mathematics and science to create benefit for humankind, the foremost objective of engineering education is to assist undergraduates in practicing engineering. Especially, it was agreed that the conventional method of teaching by lecturing is ineffective in science and engineering education. That is, a cycle begins with theoretical conceptualization followed by conducting an experiment that leads to a substantial experience and improves the overall observed reflection [1-3].

Since most engineering practices are performed in the laboratory, theory is coupled with practice to enhance the learning quality and to gear fresh graduate engineers to operate, process, design, and optimize chemical plants. It's worth mention to differentiate between teaching laboratory and other educational development and research laboratories. A development laboratory is essential to guide practicing engineers in rendering and optimizing a product in terms of answering specific questions of immediate importance to assess if the mockup is as functional as planned. While a research Laboratory, on the other hand, is intended to seek broader understanding and boost overall knowlege that can be helpful for other researchers or developers, but often without any particular application in mind. In contrast, teaching or instructional laboratory is a place for students to better undertand and discover a concept or relation through a well-designed learning objective [4].

Teaching laboratory is a vital part of engineering education where engineering instructions and hands-on practice take place in the laboratory [5]. It is worthy of mentioning that the curricular objective of this type of laboratories is to relate theoretical principles and practical experience than just conventional class teaching [6-10]. Moreover, it provides students with a virtual sense of physical items in addition to developing the feel for engineering [11,12]. Expressly, the laboratory fosters the improvement of a deep understanding of basic learning through practice.

Studies have indicated that conceptions of science and engineering education can be categorized into two levels of learning; low or primary and higher or advanced. The primary level ofs learning includes memorizing, testing, and calculating learning activities. These activities are practiced in the classroom, and they enhance reproductive learning strategies that help students to acquire knowlege and accumulate the required content. In contrast, the advanced level of learning comprises higher broadminded learning activities like broadening knowlege, implementing, observing, and considering facts from another standpoint. When these activities of the advanced level of learning are implemented in labs, they promote constructive learning strategies and foster the absorption of more complicated subjects [13-21].

Teaching Lab evolution: Alternatives to traditional hands-on laboratories

In the early twentieth century, both "American Engineering accreditation" and the "American Institute of Chemical Engineers" (AIChE) indicated the significance of laboratories in the engineering curriculum, and they together started the process of accreditation that impacted the quality of teaching laboratories obviously [22, 23]. Although these concerted efforts are to ensure the quality of teaching in conventional Labs where students conduct experiments by following written procedures in a Lab manual. It is believed that these types of laboratories may not succeed in engaging students in the thoughtful learning activities that required for cognizing the fundamental concepts. Here, three types of laboratories have been proposed as an unconventional approach to mitigate the limitation of conventional Labs, which are Inquiry-based, Fabrication, and Living laboratory.

A) Inquiry-Based Laboratory

An inquiry-based laboratory permits students to select their conducted experiments. Consequently, students have to impose their experience and knowlege to deal with challenges related to realistic situations [24,25]. This type of laboratory was implemented by introducing it as a Lab module in the biomedical engineering physiology course by Lisenmeier and co-workers [26], and the results showed a significant improvement for the inquiry-based sample in comparison with the control sample. In another study, the influence of the inquiry-based laboratory was investigated on junior students in the environmental Engineering course during the last four weeks of the semester [27]. The study reveals that the inquiry-based laboratory assists students in realizing and understanding the environmental concepts profoundly compared to traditional Laboratories.

Other institutions have implemented a progressive hands-on practice for students to promote and support the instructional laboratory. At "Imperial College London", the three-stage hands-on practice was implemented for undergraduate students during their first three years of engineering education. The level of freedom for each stage rises with their competencies. In the first stage, students are requested to conduct the instructed experiments safely and accurately under full supervision, then in the second stage, they are given certain research topics, and they are allowed to design their experiments under a monitor's observation to achieve the research goal. Finally, in the most advanced third stage laboratory, students are free to plan their own research goals and project accordingly [28,29].

B) Fabrication Laboratory

In the last years, a new type of laboratories has emerged that promotes the students' creativity and gives them the possibility to turn their ideas into prototype and products through 3D modeling, rendering, fabrication, optimization, and validation of their projects. This category of laboratories is well-known as "Fab Labs" (an abbreviation of "Fabrication Laboratories") and become a new trend in engineering education [30,31]. It initiated as an educational module at the "Center for Bits and Atoms" (CBA), and currently, its network covers 30 countries. The importance of Fab Labs has increased in the last years due to the unique features and privileges it provides. For instance, the product can be modified without affecting the design of other parts; also, it can be used for the recycling of waste plastics into valuable products [30]. Introducing Fab Labs in engineering education promotes inspiration and creativity among students. In addition, helping students create their own prototype using novel techniques of digital manufacturing foster a swift improvement in engineering education [32].

C) Living Laboratory

Another unique type of laboratory that has emerged recently to provide a novel approach to boost teamwork and creative thinking using user centricity's environment is living laboratory [33]. Living Labs have been established in Europe and the United States educational institutions to help students' imagination and creativity by challenging them with uncommon real-life complicated scenarios [34-36]. Results of implementing Live Labs in the undergraduate computer science curriculum reveal optimistic acceptance for use to sharpen students' problem-solving skills [37]. In another study in China, Living Laboratory was introduced to mitigate traditional education limitations, especially in innovation and entrepreneurial abilities [38].

D) Remote Labs

The integration of computers and the Internet in teaching laboratories, as well as the rapid evolution of the software and network programming, enable remote control of Labs. Accordingly, distant learners are provided with remote access to physical laboratory equipment through computers that are connected to the physical experiments and used for remote controlling of equipment, data acquisition, and collection, which influences the productivity and the quality of student work through distance learning [39,40]. For example, LabVIEW software, produced by National Instruments Corporation, is one of the most comprehensive systems that combine software and hardware to convert a personal computer to a data-acquisition device that can control the equipment remotely [4]. LabVIEW distributes the data to iLab server that can be retrieved via the Internet [41].

Remote Lab offers some exclusive traits like availability, observability, accessibility, and safety [42]. Remote labs help students who are geographically dispersed because they are available anytime and can be installed anywhere. Previously, programs require practicing in their curriculum, and students were forced to either accomplish laboratory practicing at another institution or enroll in an intensive laboratory course on the engineering campus [43]. Remote labs also provide accessibility to students who have some incapacities and may become unable to access or conduct lab experiments. So, remote labs help learners exercise practical experience over the Internet. As a result, they not only magnify the use of sophisticated lab equipment but also provides Lab experience when the hands-on practice is not possible [44]. In a review study to investigate remote labs on cognitive learning outcomes in different graduate schools by Post and his team, results reveal that the conceptual knowlege of students who engaged in remote lab improved due to more available learning time as a result of a simultaneous run of remote labs [45].

Despite safety operation that remote labs offer in terms of distance location of the user away from the physical equipment, a user of the remote lab must undergo comprehensive training to acquire adequate skills to operate the equipment without causing damage to it, which foster the user motivation [46]. Remote labs have the advantage that they can be operated under distance supervision, and the trials can be saved and documented as reference for educational and training purposes [47].

Although there are unique features remote lab controlling offers, it encounters criticisms from opponents of this type of laboratories specifically for undergraduate students. For instance, in remote Labs, there is a claim that writing program codes to provide remote access to laboratories is a major challenge as some faculty have developed their own access systems instead of using commercial software [48,49]. Other institutions provide students the possibility to upload experimental parameters, and after that, they can receive a video that includes the operations using those parameters [50]. Also, the level of computerization in remote Labs might not suit undergraduate students and may, to some extent, deprives them of the direct process of the laboratory practice [4].

E) **Virtual Labs**

While conventional practical laboratories offer engineering students the opportunities of hands-on practice with physical equipment, they have some drawbacks such as high asset cost of the experiments, space requirements, and continual maintenance [51], besides the breakthrough in the computers and internet virtual labs emerged [52].

Virtual Labs (VL) evolved from simulation software, which is a result of the swift progression of programing and software platforms that provide engineers with a promised land for practicing a lot of engineering skills such as designing and testing a single operation unit up to designing and optimizing a whole complicated chemical plant. Nowadays, simulation software has become an energetic portion of engineering education and its ability to visualize and demonstrate some parameters and processes that cannot easily be visualized. Thus, virtual labs not only help to reduce the asset and maintenance costs and retain the lab space, but they are a safe substitute for those operations that might include hazards [47,51].

Nevertheless, some considerations are connected to VL with regard to the quality of learning outcomes in comparison with traditional labs. Educators who are reluctant to VL claim that simulation software is limited as it is based on basic models of physical or chemical accuracy, and however, its accuracy cannot reflect and simulate the real scenarios offered by real system. So, they can only be used as a complementary tool that can mimic different engineering processes, especially those involve physical limitation in measurements or safety hindrances, but never recommended as a substitute because they will fail in emulating complex systems. Consequently, despite the increased power and efficiency of simulation programs today, they cannot entirely replace traditional lab experiments [53-56].

However, while some educators state that remote laboratories lead to more isolation among students, which harmfully affects learning outcomes, others mitigate this isolation from the learning process by creating teams to provide a collaborative involvement for students [49, 57]. Moreover, most empirical studies declare that the learning outcome of VL is as good as conventional Labs [58-63]. While 2D visualization is dominant in VL, 3D imaging is the feature of "virtual reality" (VR), "immersive virtual reality" (IVR), "mixed virtual reality" (MVR), and "augmented reality" (AR), which are new advanced technologies added to VL.

The virtual world is generated using a sophisticated programing language to create an impressive sense of presence and immersion through "head mounted display" (HMD) and stereophonic sound. This type of virtual reality creates a high degree of subjectivity and autonomy to the user [64]. Based on the details of the VR, the user gains experience through diving into the simulation that mimics the real-world [65]. Several studies have evaluated the impact of (VR) on education, but the results were controversial. Although in many studies, using (VR) has boosted the learning outcome [66-72], other studies reveal that (VR) distracts students' attention and harm their learning outcome [73] and that most students depend on listening to the narration without reading text [74]. As a result of evolution in VR technology, Immersive Virtual Reality (IVR) has emerged, which is referred to as the act of immersion of oneself into another virtual world [75]. IVR was found to be more effective in studying than reading scripts or interacting with simulations on PC. [76,77].

In contrast with VR that replaces one's vision, augmented reality (AR), on the other hand, adds to it. In other words, AR boosts human perception through embedding 2D or 3D virtual elements in the real-world environment [78,79]. Implementing AR in the traditional laboratory was found to expand students' conceptual knowlege and cognitive skills [80-84].

Urgent need for remote and virtual Labs to mitigate the impact of COVID-19 confinement on higher education

No one can deny that engineering education cannot be performed without practicing, as laboratories gear students up for practicing engineering. However, since the early spring of 2020, the global world has been hindered by the pandemic COVID-19 outbreak. In response, to diminish the spread of this pandemic, governments around the world have taken precautionary actions to ensure their citizens' safety. Consequently, education has affected intensely. For instance, on-campus activities have been suspended in many universities and substituted by online education. Other universities prefer to suspend the teaching until further notice or postpone the study to the summer semester [85,86].

Due to the unexpected and sudden migration from the traditional way of education to online approach, impact principles and instructional strategies should be identified and implemented to ensure the effectiveness of online education. In a case study at Peking University's, five impact principles were identified [87];

1) The online instructions should be highly relevant to student learning outcome
2) The online information should be effectively delivered
3) Students should receive sufficient support from faculty
4) Students should participate effectively during the online sessions to improve their learning outcome
5) Preparing an emergency plan to deal with any contingency in the educational platform.

In order to enhance learning outcome and encourage students' engagement in the online education Bao [87] classified six educational strategies for this purpose:

1) Splitting the course content into small units to help students to concentrate effectively
2) Working with teaching assistant to the teaching to provide effective assistance to students at different teaching activities
3) Preparing preparedness plans for popup problems
4) Consolidating students' learning activities outside of class such as reading assignment, projects or homework, focusing on vocal expression instead of facial expression and body language, which are restricted in the online education
5) Guiding and encouraging students to combine online learning with self-learning activities.

Unfortunately, due to the few published studies, the impact of COVID-19 on the educational outcome is still ambiguous. For instance, COVID-19 confinement influenced the students' performance in a recent study to investigate the pandemic quarantine on 458 undergraduates' educational outcomes from different subjects in Spain. The authors attribute this boost to the change in students' approaches from a discontinuous to continuous learning habit [88]. In contrast, other studies show the opposite impact on college students in China, such as a delay in academic activities [89]. This retardation in the education process is attributed to the prevalence of depression and stress associated with fear and inadequate sleep duration, and these symptoms are aggregated among senior students who are about to graduate [90].

Conclusion

Due to the unexpected and sudden migration from the traditional way of education to online approach, remote and virtual laboratories can be an effective alternative lab teaching option. Despite some limitations associated with online lab teaching, the advantages related to learning outcome overweigh its drawbacks.

References

1. Freeman S, Sarah LE, Miles MD, Michelle KS, Hannah J et al. (2014) Active learning increases student performance in science, engineering, and mathematics. PNAS 111(23): 8410-8415.
2. Waldrop MM (2015) Why we are teaching science wrong, and how to make it right. Nature 523(7560): 272-274.
3. Alice Y, Kolb Y, David AK (2005) Learning styles and learning spaces: enhancing experiential learning in higher education. Academy of Management Learning & Education 4(2): 193-212.
4. Feisel LD, Rosa AJ (2013) The role of the laboratory in undergraduate engineering education. JEE 94(1): 121-130.
5. Grayson LP (1993) The Making of an Engineer. CRC Press, Ohio, United States.
6. Johnson SH, Luyben WL, Talheim DL (1995) Undergraduate Interdisciplinary Controls Laboratory. Journal of Engineering Education 84(2): 133-136.
7. Flack K, Volino RJ (1999) Series-parallel heat exchanger experiment. Journal of Engineering Education 88(1): 27-30.
8. Bisantz AM, Paquet VL (2002) Implementation and evaluation of a multi-course case study for framing laboratory experiments. Journal of Engineering Education 91(3): 299-307.
9. Olinger DJ, Hermanson J (2002) Integrated thermal-fluid experiments in WPI'S discovery classroom. Journal of Engineering Education 91(2): 239-243.
10. Okamura AM, Richard C, Cutkosky MR (2002) Feeling is believing: using a force-feedback joystick to teach dynamic systems. Journal of Engineering Education 91(3): 345-349.
11. Leva A (2003) A hands-on experimental laboratory for undergraduate courses in automatic control. IEEE Transactions on Education 46(2): 263-272.
12. Moore DJ, Voltmer DR (2003) Curriculum for an engineering renaissance. IEEE Transaction on Education 46(4): 452-455.
13. Myrskog EG (1998) Students' conceptions of learning in different educational contexts. Higher Education 35(3): 299-316.
14. Marshall DM, Mike S, Woolnough B (1999) Students' conceptions of learning in an engineering context. Higher Education 38(3): 291-309.
15. Marton F, Dall Alba G, Beaty E (1993) Conceptions of learning. International Journal of Educational Research 19(3): 277-300.

16. Roger S (1979) Learning in the learner's perspective I some common-sense conceptions No. 76. Swedish Council for Research in the Humanities and Social Sciences, Stockholm. pp. 1-25.
17. Tsai CC (2004) Conceptions of learning science among high school students in Taiwan: A phenomenographic analysis. International Journal of Science Education 26(14): 1733-1750.
18. Lin CC, Tsai CC (2009) The relationships between students' conceptions of learning engineering and their preferences for classroom and laboratory learning environments. The Journal of Engineering Education 98(2): 193-204.
19. Lee MH, Johanson RE, Tsai CC (2008) Exploring Taiwanese high school students' conceptions and approaches to learning science through a structural equation modeling analysis. Science Education 92(2): 191-220.
20. Burnett PC, Pillay H, Dart BC (2004) The influences of conceptions of learning and learner self-conception on high school students' approaches to learning. School Psychology International 24(1): 54-66.
21. Purdie N, Hattie J (2020) Assessing students' conceptions of learning. Australian Journal of Educational & Developmental Psychology 2: 17-32.
22. Reynolds TS (1983) 75 years of progress: A history of the American institute of chemical engineers, 1908-1983. American Institute of Chemical Engineers, New York, USA.
23. (1888) Setting the stage for a new profession, chemical engineering in 1888.
24. Sheppard S, Macatangay M, Colby A, Sullivan WM, Shulman LE, et al. (2009) Educating engineers: Designing for the future of the field. Jossey-Bass, USA.
25. Hazel E, C Baillie (1998) Improving teaching and learning in laboratories. Higher Education Research and Development Society of Australasia.
26. Lisenmeier RA, Kanter DE, Smith KD, Linsenmeier KA, Mckenna AF, et al. (2008) Evaluation of a challenge-based human metabolism laboratory for undergraduates. Journal of Engineering Education 97(2): 213-222.
27. Flora JRV, Cooper AT (2005) Incorporating inquiry-based laboratory experiment in undergraduate environmental engineering laboratory. Journal of Professional Issues in Engineering Education and Practice 131(1): 19-25.
28. Chen W, Shah U, Brechtelsbauer C (2016) The discovery laboratory - a student-centred experiential learning practical: Part I - overview. Education for Chemical Engineers 17: 44-53.
29. Chen W, Shah UV, Brechtelsbauer C (2019) A framework for hands-on learning in chemical engineering education-training students with the end goal in mind. Education for Chemical Engineers 28: 25-29.
30. Alíaa C, Ocana R, Caja J, Maresca P, Diaz CM, et al. (2019) Use of open manufacturing laboratories (Fab Labs) as a new trend in engineering education. Procedia Manufacturing 41: 938-943.
31. Fab Lab foundation web- What is a Fab Lab?
32. Byard DJ, Woern AL, Oakley RB, Fielder MJ, Snabes SL, et al. (2019) Green fab lab applications of large-area waste polymer-based additive manufacturing. Additive Manufacturing 27: 515-525.
33. Birgitta BK, Carnia IE, Anna S, Jesper S (2009) A milieu for innovation-defining living labs. Proceedings of the 2nd ISPIM Innovation Symposium, New York City, USA,
34. Kareborn BB, Hoist M, Stahlbrost A (2009) Concept design with a living lab approach. 42nd Hawaii International Conference on System Sciences, Big Island, USA.
35. Kipling R, Miarnes M (2011) Broad implementation: Creating communities of learners for information cognitive science education.
36. Mendes C, Silvia N, Silvia M, Mira da Silvia M (2016) Automated business process management. 7th International Conference, IESS 2016, 274: 287-298.
37. French JH, Cox C, Murphy AA (2013) A living lab approach for collaboration and innovative thinking in the CS curriculum. Proceedings of the 51st ACM Southeast Conference 38: 1-2.
38. Huadong L, Yanjun S, Shuren Z (2009) Cultivation of innovative and entrepreneurial undergraduates based on the concept of living lab: Theory and practice. International Conference on Scalable Computing and Communications; Eighth International Conference on Embedded Computing Scalable Computing and Communications.
39. Gillett, D, Latchman HA, Salzmann, Crisalle OD (2001) Hands-on laboratory experiments in flexible and distance learning. Journal of Engineering Education 90(2): 187-191.
40. Kikuchi T, Fukuda S, Fukuzaki A, Nagaoka k, Tanaka K, et al. (2004) DVTS-based remote laboratory across the pacific over the gigabit network. IEEE Transactions on Education 47(1): 26-32.
41. Trentsios PM, Wolf, Frerich S (2020) Remote lab meets virtual reality enabling immersive access to high tech laboratories from afar. Procedia Manufacturing 43: 25-31.
42. Gravier C, Fayolle J, Bayard B, Ates M, Lardon J (2008) State of the art about remote laboratories paradigms foundations of ongoing mutations. International Journal of Online and Biomedical Engineering 4(1): 19-25.
43. Bengiamin NN, Johnson A, Zidon M, Moen D, Ludlow DK (1998) The development of an undergraduate distance learning engineering degree for industry-a university/industry collaboration. Journal of Engineering Education 87(3): 277-282.
44. PA (1999) Report on the nfs/css workshop on new directions in control engineering education. IEEE Control Systems Magazine. pp. 53-58.
45. Post LS, Guo P, Saab N, Admiraal W (2019) Effects of remote labs on cognitive, behavioral, and affective learning outcomes in higher education. Computers & Education 140: 1-9.
46. Luthon F, Larroqueet B, Khattar F, Dornaika F (2017) Use of gaming and computer vision to drive student motivation in remote learning lab activities, in ICERI 2017: 10th annual International Conference of Education, Research and Innovation. Seville, Spain.
47. Gravier, C., et al., State of the art about remote laboratories paradigms foundations of ongoing mutations. International Journal of Online Engineering, 2008. 4(1): 9-25.
48. Guimaraes E, Maffeis A, Pereira J, Russo B, Cardozo E, et al. (2003) Real: A virtual laboratory for mobile robot experiments. IEEE Transactions on Education 46(1): 37-42.
49. Hoyer H, Jochheim A, Rohrig C, Bischoff A (2004) A multiuse virtual-reality environment for a tele-operated laboratory. IEEE Transactions on Education 47(1): 121-126.
50. Esche SK, Chassapis C, Nazalewicz JW, Hromin DJ (2002) A scalable architecture for remote experimentation in 32nd ASEE/IEEE Frontiers in Education Conference. Boston, USA.
51. Gomes L, Bogosyan S (2009) Current trends in remote laboratories. IEEE Transactions on Industrial Electronics 56(12): 4744-4756.
52. Dormido S (2004) Control learning: present and future. Annual Reviews in Control 28(1): 115-136.
53. http://www.ecircuitcenter.com/?S%20piceTopics/Limitations.htm.
54. Baher J (1999) Articulate virtual labs in thermodynamics education: A multiple case study. Journal of Engineering Education 88(4): 429-434.
55. Lee WJ, Cherng Gu J, Jun Li R, Didsayabutra P (2002) A physical laboratory for protective relay education. IEEE Transactions on Education 45(2): 182-186.

56. Svajger J, Valencic V (2003) Discovering electricity by computer-based experiments. IEEE Transactions on Education 46(4): 502-507.

57. Sebastian JM, Garcia D, Sanchez FM (2003) Remote-access education based on image acquisition and processing through the internet. IEEE Transactions on Education 46(1): 142-148.

58. Gustavsson I, Nilsson K, Zackrisson J, Zubia JG, Jayo UH, et al. (2009) On objectives of instructional laboratories, individual assessment, and use of collaborative remote laboratories. IEEE Transactions on Learning Technologies 2(4): 263-274.

59. Kostaras N, Xenos M, Skodras A (2011) Valuating usability in a distance digital systems laboratory class. IEEE Transactions on Education 54(2): 308-313.

60. Lindsay E, Good M (2005) Effects of laboratory access modes upon learning outcomes. IEEE Transactions on Education 48(4): 619-631.

61. Nedic Z, Machotka J, Nafalski A (2003) Remote laboratories versus virtual and real laboratories. Annual Frontiers in Education Conference, USA.

62. Nickerson JV (2007) A model for evaluating the effectiveness of remote engineering laboratories and simulations in education. Computers & Education 49(3): 708-725.

63. Sicker D (2005) Assessing the effectiveness of remote networking laboratories. Proceedings Frontiers in Education Conference. USA.

64. Slater M, Sanchez MV (2016) Enhancing our lives with immersive virtual reality. Frontiers in Robotics and AI.

65. Chavez B, Bayona S (2018) Virtual reality in the learning process, in trends and advances in information systems and technologies. pp: 1345-1356.

66. Jou M, Wang J (2013) Investigation of effects of virtual reality environments on learning performance of technical skills. Computers in Human Behavior 29(2): 433-438.

67. Cruz JAS, Sabrina T, Rodrigo M, Ricardo J, Hiep N, et al. (2016) Does warm-up training in a virtual reality simulator improve surgical performance? A prospective randomized analysis. J Surg Educ 73(6): 974-978.

68. Tüzün H, Özdinç F (2016) The effects of 3D multi-user virtual environments on freshmen university students conceptual and spatial learning and presence in departmental orientation. Computers & Education 94: 228-240.

69. Rusiñol M, Chazalon J, Diaz KC (2018) Augmented songbook: An augmented reality educational application for raising music awareness. Multimedia Tools and Applications 77(11): 13773-13798.

70. Merchant Z, Ernest T, Lauren C, Wendy K, Trina J (2014) Effectiveness of virtual reality-based instruction on students' learning outcomes in K-12 and higher education: A meta-analysis. Computers & Education 70: 29-40.

71. Concannon BJ, Esmail S, Roduta MR (2019) Head-mounted display virtual reality in post-secondary education and skill training. Frontiers in Education.

72. Meyer OA, Omdahl MK, Makransky G (2019) Investigating the effect of pre-training when learning through immersive virtual reality and video: A media and methods experiment. Computers & Education 140.

73. Parong J, Mayer RE (2018) Learning science in immersive virtual reality. Journal of Educational Psychology 110(6): 785-797.

74. Makransky G, Terkildsen TS, Mayer RE (2019) Adding immersive virtual reality to a science lab simulation causes more presence but less learning. Learning and Instruction 60: 225-236.

75. Sherman W, Craig A (2018) Understanding virtual reality: Interface, application, and design. A volume in The Morgan Kaufmann Series in Computer Graphics.

76. Zinchenko YP, Khoroshikh PP, Sergievich AA, Smirnov AS, Tumyalis AV, et al. (2020) Virtual reality is more efficient in learning human heart anatomy especially for subjects with low baseline knowledge. New Ideas in Psychology 59: 100786.

77. Fealy S, Donovan J, Alison H, Kristen G, Linda S, et al. (2019) The integration of immersive virtual reality in tertiary nursing and midwifery education: A scoping review. Nurse Educ Today 79: 14-19.

78. Cheng KH, Sai CCT (2012) Affordances of augmented reality in science learning: Suggestions for future research. Journal of Science Education and Technology 22(4): 449-462.

79. Ibáñez MB, Delgado CK (2018) Augmented reality for STEM learning: A systematic review. Computers & Education 123: 109-123.

80. Altmeyer K, Sebastian K, Michael T, Sarah M, Jochen K, et al. (2020) The use of augmented reality to foster conceptual knowledge acquisition in STEM laboratory courses-Theoretical background and empirical results. British Journal of Educational Technology 51(3): 611-628.

81. Dounas Frazer DR, Lewandowski HJ (2018) The modelling framework for experimental physics: description, development and applications. European Journal of Physics 39(6): 064005.

82. Jochen Kuhn, Paul Lukowicz, Michael Hirth, Andreas Poxrucker, Jens Weppner, et al. (2016) gPhysics-using smart glasses for head-centered, context-aware learning in physics experiments. IEEE Transactions on Learning Technologies 9(4): 304-317.

83. Bujak KR, Radu I, Catrambone R, MacIntyre B, Zheng R, et al. (2013) A psychological perspective on augmented reality in the mathematics classroom. Computers & Education 68(C): 536-544.

84. Michael Thees, Sebastian Kapp, Strzys MP, Fabian Beil, Paul Lukowicz, et al. (2020) Effects of augmented reality on learning and cognitive load in university physics laboratory courses. Computers in Human Behavior 108.

85. Impact of COVID-19 on studying abroad in Europe: Overview. 2020. p. https://www.study.eu/article/impact-of-covid-19-on-studying-abroad-in-europe-overview.

86. How is Covid-19 affecting schools in Europe? 2020. p. https://eacea.ec.europa.eu/national-policies/eurydice/content/how-covid-19-affecting-schools-europe_en.

87. Bao W (2020) COVID-19 and online teaching in higher education: a case study of peking university. Human Behavior and Emerging Technologies 2(2): 113-115.

88. Gonzalez T, De La Rubia MA, Hincz KP, Lopez CM, Subirats L, et al. (2020) Influence of COVID-19 confinement in students performance in higher education. arXiv:2004.09545 [cs.CY].

89. Cao W, Fang Z, Hou G, Han M, Xinrong Xu, et al. (2020) The psychological impact of the COVID-19 epidemic on college students in China. Psychiatry Res 287: 112934.

90. Tang W, Tao Hu, Baodi Hu, Jin C, Gang Wang, et al. (2020) Prevalence and correlates of PTSD and depressive symptoms one month after the outbreak of the COVID-19 epidemic in a sample of home-quarantined chinese university students. J Affect Disord 274: 1-7.