Research Challenges in future laboratory-based STEM Education

I. E. Lasica, K. Katzis, M. Meletiou-Mavrotheris, and C. Dimopoulos

***Abstract*— Science, Technology, Engineering and Mathematics (STEM) Education is strongly supported by laboratory experiments, which constitute a significant educational tool to promote better understanding among students. Virtual and Remote Labs have become an interesting field of study during the past two decades. Several studies have been devoted to the different types of labs arising with the evolution of technology and their efficacy within all educational levels. In this conceptual paper, some current trends are identified after a brief overview of the state-of-the-art concerning laboratory experiments within secondary / higher education and lifelong learning. Moreover, challenges are discussed and potential future areas of research are identified. The overarching aim of these research areas is to assess the usefulness, effectiveness, acceptability, adaptability, social impact and cost of the described types of laboratories to fulfill the high standards required for a career in a STEM related profession.**

***Index Terms*—Augmented Reality, Distance Learning, Remote Labs, Virtual Labs.**

I. Introduction

Science, Technology, Engineering and Mathematics (STEM) Education is an area receiving increased attention during the past decades not only within the educational but also the commercial and the entertainment field. Experiments constitute a critical part of the engineering education since they attract students' interest, promote better understanding of the taught theories, and provide opportunities for the acquisition of practical knowledge.

The evolution of technology offers new opportunities in lab-based STEM education, overcoming the drawbacks of using traditional hands-on labs such as high costs, limited availability, expensive maintenance, etc. [1] [2]. Modern approaches have been initiated including remoteness (remote labs), virtuality (virtual labs) and recently immersion (augmented reality labs) [3] [4]. The new types of labs provide important benefits, including reduced costs, enhanced availability and accessibility, large-scale observability, and increased safety [5]. A significant number of studies underline the potential of laboratory-based learning for the enhancement of the educational process within traditional classrooms or within an e-learning and/or a b-learning context [3] [6] [7].

In spite of the numerous benefits and the popularity of laboratory experiments within STEM education, there are still some drawbacks that need to be addressed concerning remote labs [8]. Some of the limitations mentioned in different studies are the following: (a) virtual environments are imitations of reality and thus suffer from a weak realistic representation of real equipment [9]; (b) virtual and augmented reality labs enhance students' isolation [3]; (c) since data are obtained from theoretical calculations based on mathematical models, students often fail to take into account instrument or other errors inherent in practical experimentation [9].

The main research question of this work, steamed from the NeReLa Project's objectives (a TEMPUS project carried out with partners from Serbia and EU - Slovenia, Spain, Portugal, Cyprus and Greece), including teachers' inspiration (Higher and Secondary Vocational Education) in Serbia to take advantage of remote labs as a means of enhancing engineering teaching and making it more effective and attractive. In this conceptual paper, we identify current trends in laboratory-based STEM education by drawing upon existing research articles and bibliometric analyses in the field of virtual and remote labs in education [2] [3] [6] published in international high-rated journals in the field of education, computer sciences, and information technology. The analysis was exploratory and based on 30 papers which were reviewed to draw the conclusions while results of recent extensive analyses in the field were referred as main foundations to be extended. The keywords used in our search for relevant literature included terms like Virtual Laboratory, Remote Laboratory, Augmented Reality and STEM. Further selection criteria for articles reviewed included the following: (a) published during the last ten years (2006-2016) so as to reflect recent trends, (b) explicitly addressing the STEM field; and (c) reporting on technologies related to laboratory education.

After a brief overview of the state-of-the-art concerning laboratory experiments within STEM-related education and distance learning, we describe the different lab types identified within studies so far and their main characteristics. Moreover,

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some current trends are distinguished and some additional challenges are pointed out as identified in the bibliography. These challenges could become areas of further scientific research interest, referring to the usefulness, effectiveness, acceptability, adaptability, social impact and cost of the described types of laboratories. More specifically, Section 2 introduces the reader to various types of laboratory-based education, Section 3 discusses laboratory-based STEM education and presents a number of examples of remote laboratories, and Section 4 describes the research challenges and research directions that need addressing. Finally, conclusions are drawn.

II. Types of Laboratory-Based Education

As already mentioned, experiments constitute a critical part of STEM since they enhance students' understanding of the theories taught. However, an important question arising from the literature review is the variety of types of labs one can identify when implementing an experiment. This section describes the specific characteristics of each type of lab, as recognized by us and categorized by Villalba et al. [4] according to: (a) the way resources are accessed (remote or local) and (b) the physical nature of the lab (simulated or real). Taking into consideration a blended category mentioned within recent studies as "augmented", which combines virtual with real equipment, we have added it as an extra category [5] [10].

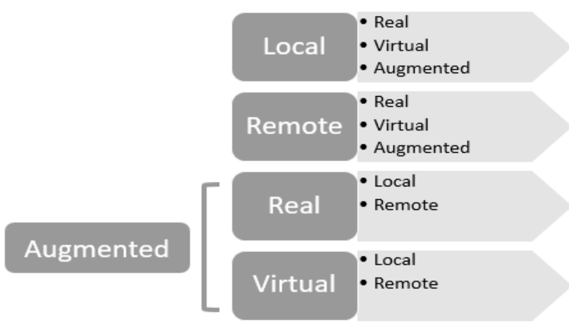

Fig. 1. Lab categories concerning resources access and physical nature.

According to the way resources are accessed, labs could be distinguished between *local* and *remote*. More specifically, traditional hands-on labs, existing in a specific physical location (within a school, a university or anywhere experiments can take place), could be considered as local labs where students implement an experiment in real time (synchronous) mode. Usually only a single student or a small group of students participate in the implementation of the experiments. Local Labs, as presented in Figure 1, could include Real Local Labs (RLLs), Virtual Local Labs (VLLs) and Augmented Reality Local Labs (ARLLs), referring to the physical nature of the lab [11]. Remote labs differ in such a way that they allow students to perform experiments in real-time (synchronously) or at a time of their own choice (asynchronously) through the Internet [12]. Remote Labs, as presented in Figure 1, could include Real Remote Labs (RRLs), Virtual Remote Labs (VRLs) and Augmented Reality Remote Labs (ARRLs) referring to the physical nature of the lab [11]. Figure 1 illustrates the combinations based on the categories mentioned.

III. Laboratory-based STEM Education

There is a general agreement on the benefits of labs to teach science and engineering [2] [13] [14]. Local and Remote labs, as presented in Figure 1, are not exclusive alternatives, but they are valuable educational resources which could be combined in one integral and complementary curriculum concerning STEM education [15] [16].

A number of studies cast doubt on the effectiveness of VRLS within the educational process, underlining that RLLs are necessary to acquire haptic skills and instrumentation awareness, skills difficult to achieve through VRLs and ARRLs [16] [17]. These studies emphasize the need for employing a combination of the different types of labs during different educational phases, e.g. VRLs during preparation, RLLs in live lectures in order to implement real experiments and finally, RRLs to support repetitive experimentation [16].

The most common consensus within studies concerning laboratory-based STEM education, is that virtual labs constitute a useful tool for students to implement experiments without space or time limitations, as opposed to local laboratories which are limited to a specific place and time constraints [3] [14]. Some studies also mention that bringing remote experiments into classrooms (secondary, higher, secondary-vocational education etc.) is an efficient way to achieve better learning outcomes [18], and to attract students to STEM related fields of study and careers [19].

As part of our research activities at EUC, we have been involved in a Tempus project called Network of Remote Laboratories (NeReLa) along with our partners from Serbia, Slovenia, Spain, Portugal, etc. [20]. NeReLa aimed at inspiring university teachers (Higher Education) as well as school teachers of secondary vocational education in Serbia, to take advantage of remote labs as a means of enhancing engineering teaching and making it more effective and interesting [21]. Some remote and virtual experiments were developed and carried out within the laboratories of partner universities, thus enhancing the NeReLa library of remote experiments for further use. Examples of remote laboratories demonstrated by partner universities are described below:

(a) **University of Maribor:** Two solutions for RRLs were proposed: (i) an in-house developed remote control laboratory and (ii) an external remote laboratory, based on CEyeClon network [22]. Both were integrated with a Moodle Learning Management System for the booking process. The university's RRLs are included into three networks: (1) EDIPE [23], (2) E-PRAGMATIC [24] and (3) SustEner [25].

(b) **University of Deusto:** A remote laboratory for multidisciplinary experimentation was presented, based on an open-source Remote Laboratory Management System. WebLab-Deusto was designed to enhance the development of RRLs supporting all necessary features to deploy a remote lab, such as authentication, authorization, scheduling, load balancing, user tracking, sharing and administrative tools [18] [20]. Three main experiments were performed within WebLab-Deusto, VISIR LXI (with real electronic circuits), WebLab-Bot (for programming a microcontroller based on a popular mobile robot) and WebLab-Box (for performing Field Programmable Gate Array (FPGA) based embedded systems).

(c) **Faculty of Engineering of University of Porto (FEUP):** The first remote laboratory of sensitive type (Meteorological Station) was provided on a regular basis in 1998. Many projects' funding have promoted the sharing of remote labs and technical expertise within the university's repository since then. In 2010 a wide goal was set· the creation of a consortium in Portugal of online experimentation and a relative platform, to initialize a database for retrieving all national initiatives in remote and virtual labs, following the International Association of Online Engineering (IAOE) ontology [18]. Such a repository would be able to promote collaborative activities and foster the sharing of resources at national level and generally, in Portuguese speaking countries. Within this goal, FEUP has been sharing relative resources with national and international institutions.

The abovementioned case studies mostly referred to technologies concerning RRLs, whereas some of the experiments introduced Augmented Reality similarly to other studies [5]. NeReLa is modelled based on the available infrastructure for remote experimentation at partner universities and, by allowing people from other institutions to contribute towards developing new remote engineering experiments, is expected to enrich LiReX library, a "living organism" collection of remote experiments within European institutions.

IV. Research Challenges and Research Directions

There is an obvious trend in education towards the extensive use of different types of labs, generally in the field of STEM and especially in the field of engineering [1]. Laboratory-based education has been spreading across all educational levels (primary schools, higher education, vocational learning, universities etc.) from self-education to formal curricula [3] [8]. Moreover, there are studies that focus on virtual learning environments concerning special categories of students (e.g. students with autism) [26]. The use of virtual environments can enhance students to acquire more specific technical skills, which can be considered as essential 21st century skills for lifelong learning.

We believe that there are many research areas worth investigating related to laboratory-based STEM education [18] [20]. Heradio et al. [3] specify four main areas for intensive research which could be developed in the near future: (a) efficient combination of virtual and remote labs, (b) collaborative learning, (c) VRLs assessment, and (d) VRLs sharing. Additionally to these specific areas, some studies have identified the need to build platforms with the capability of adaptation to different users' profiles [15] [27], which should take into consideration the specific needs of a user and his/her background (such as educational level (e.g. secondary education), knowledge field (e.g. engineering), role (e.g. student, trainee) and suggest relative experiments.

Moreover, the assessment of the educational effectiveness of the different types of laboratories presented in this paper is an interesting topic for further research, in order to define whether the use of innovative ways to implement experiments can lead to higher performing students [13] [18]. Establishing RLs within current formal curricula would bring an innovative pedagogical approach to STEM education [16] and maybe introduce the basis for a fully online Engineering degree. This could lead to new Instructional Design approaches within Distance and Blended Learning, based on the usage of RRLs, VRLs and ARRLs. Additionally, collaboration within such approaches should be enhanced, through Learning Management Systems (LMS) like Moodle and social networks, as many studies mention isolation as an important drawback of RLs [28].

Another topic worth mentioning for further research, taking into consideration the objectives of projects such as NeReLa, could be the increase in the number of students choosing to follow STEM related studies. Attractiveness of STEM has already improved since relevant games and equipment are used not only for educational but also for entertainment purposes, providing a strong indication that industry approves this new type of teaching and learning methodology. However, an interesting study could focus on the impact of the different types of labs on students' professional choices.

Concerning VRLs sharing and reuse - a hot topic for further study [3] - methodologies of forming specific metadata could be proposed for organizing such repositories and defining the way and the context in which they could be used to facilitate search, retrieval and reuse processes [28]. Finally, measuring the cost of modern labs (including setup, running and maintenance) would be beneficial for academic institutions, since it would enable them to define if the running costs of these labs could decrease and as a result lower tuition fees could be achieved to enhance access to STEM education.

We believe that research directions with respect to STEM laboratories should be answering critical and practical questions at the same time in order to assist academics and academic institutions to choose the best possible way of implementing a laboratory-based pedagogical approach, so as to enhance its learning impact. Such questions include the following: *Which laboratory is most suitable for a STEM course / degree? What is the expected impact on students' skills? Does this approach fulfill the learning outcomes set at the beginning of the course? Is it too complicated and expensive to implement? Does the student require expensive equipment to be able to participate? What is the industry's opinion regarding this matter? Would employers prefer someone who has conducted most of his/her experiments remotely or would they choose a candidate with conventional studies? Can the laboratories be frequently updated or is this difficult to do due to the cost and complexity of the system to make changes to the current syllabus?* These are some of the questions someone might have to attend to before selecting between the different types of labs currently available.

V. Conclusions

To conclude, in this conceptual paper, we drawn upon existing bibliometric analyses in the field of virtual and remote labs in education and other relevant literature, in order to specify: (a) the different lab types identified within conducted to-date, and (b) some additional challenges to these mentioned within the existing bibliography that could become areas of further scientific interest, referring to useful research areas related to the usefulness, effectiveness, acceptability, adaptability, social impact and cost of the described types of laboratories. There is an obvious trend in education towards the extensive use of RRLs, VRLs and ARRLs, generally in the field of STEM and especially in the field of engineering. Finally, these topics could be main areas of focus for interesting research studies to be conducted in the future.

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References

[1] J. Ma, J. Nickerson, “Hands on, simulated and remote laboratories: A comparative literature review”, *ACM Computing Surveys*, vol. 38, no.3, 2006.

[2] L. Gomes, S. Bogosyan, “Current trends in remote laboratories”, *IEEE Transactions on Industrial Electronics,* vol. 56, no. 12, pp. 4744–4756, 2009.

[3] R. Heradio, L. de la Torre, D. Galan, F. J. Cabrerizo, E. Herrera-Viedma, S. Dormido, “Virtual and remote labs in education: A bibliometric analysis”, *Computers & Education*, pp. 9814-38, 2016.

[4] C. M. Villalba, A. U. Moraleda, S. D. Bencomo, “Distance Education On Virtual-Lab Implementation For Science Teachers”, *RIED Revista Iberoamericana de Educación a Distancia*, *11*(2), 2008.

[5] S. Odeh, S. A. Shanab, M. Anabtawi, R. Hodrob, “A Remote Engineering Lab Based on Augmented Reality for Teaching Electronics”, *International Journal of Online Engineering*, vol. 9, 2013.

[6] C. Gravier, J. Fayolle, B. Bayard, M. Ates, J. Lardon, “State of the art about remote laboratories paradigms - foundations of ongoing mutations, *International Journal of Online Engineering*, vol. 4, no. 1, pp. 19–25, 2008.

[7] R. Krneta, M. T. Restivo, A. Rojko, D. Urbano, “Evaluation of remote experiments by different target groups: NeReLa project case study”, in *2016 13th International Conference on Remote Engineering and Virtual Instrumentation (REV),* pp. 326-331, IEEE, 2016.

[8] M. Zappatore, A. Longo, M. Bochicchio, “The bibliographic reference collection GRC2014 for the online laboratory research community”, in: Conference on Remote Engineering and Virtual Instrumentation, Bangkok, Thailand, pp. 24–31, 2015.

[9] S. Odeh, “A Web-Based Remote Lab Platform with Reusability for Electronic Experiments in Engineering Education”, *iJOE*, vol. 10, no. 4, pp. 40-45, 2014.

[10] H., Vargas, G., Farias, J., Sanchez, S., Dormido, F. Esquembre, “Using Augmented Reality in Remote Laboratories”, *International Journal of Computers Communications & Control*, vol. 8, no. 4, pp. 622-634, 2013.

[11] I. Lasica, K. Katzis, M. Meletiou-Mavrotheris, C. Dimopoulos, “STEM Education: Current and future trends in laboratory-based education”, in *3rd International Conference on Electrical, Electronic and Computing Engineering IcETRAN,* to be presented June 2016.

[12] N. Aliane, “LABNET: A Remote Control Engineering Laboratory,” Universidad Europea de Madrid, DACA, Madrid, Spain, 17 November, 2006.

[13] T. de Jong, M. C. Linn, Z. C. Zacharia, “Physical and virtual laboratories in science and engineering education”, *Science*, vol. 340, pp. 305–308, 2013.

[14] T. Karakasidis, “Virtual and remote labs in higher education distance learning of physical and engineering sciences”, in Global Engineering Education Conference (EDUCON), pp. 798-807, IEEE, 2013.

[15] A. Cardoso, M. Vieira, P. Gil, “A Remote and Virtual Lab with Experiments for Secondary Education, Engineering and Lifelong Learning Courses”, *iJOE*, vol. 8, no. S2, pp. 49-54, 2012.

[16] M. Abdulwahed, Z. K. Nagy, “The trilab, a novel ict based triple access mode laboratory education model”, *Computers & Education*, vol. 56, pp. 262–274, 2011.

[17] J. Y. Ma, J. S. Choi, “The Virtuality and Reality of Augmented Reality”, *Journal of Multimedia*, vol. 2, no.1, pp.32-37, 2007.

[18] R. Radhamani, H. Sasidharakurup, G. Sujatha, B. Nair, K. Achuthan, S. Diwakar, “Virtual labs improve student’s performance in a classroom”, in *E-Learning, E-Education, and Online Training,* pp. 138-146), Springer International Publishing, 2014.

[19] R. Krneta, A. Rojko, O. Dziabenko, T. Restivo, “NeReLa project: Building network of remote labs using EU best practice, in *Tecnologias Aplicadas a la Ensenanza de la Electronica (Technologies Applied to Electronics Teaching)(TAEE),* pp. 1-8, IEEE, 2014.

[20] Network of Remote Lanpratories, NeReLa, available at http://www.nerela.kg.ac.rs , 2016

[21] R. Krneta, “Introduction to the NeReLa project”, in *Remote Engineering and Virtual Instrumentation (REV), 2014 11th International Conference on,* pp. 386-388, IEEE, 2014.

[22] CEyeClon network, RRLs, available at http://ceyeclon.com/, 2016.

[23] Power WebLab DC components Library, available at http://www.pemcweblab.com/, 2016.

[24] E-pragmatic Project, available at http://www.e-pragmatic.eu/, 2016

[25] Sustainable Energy, available at http://www.sustener.eu/, 2016

[26] C. Volioti, T. Tsiatsos, S. Mavropoulou, C. Karagiannidis, “VLSS--Virtual Learning and Social Stories for Children with Autism”, in *2014 IEEE 14th International Conference on Advanced Learning Technologies (ICALT),* pp. 606-610, IEEE, 2014.

[27] S. Graf, C. Ives, “A flexible mechanism for providing adaptivity based on learning styles in learning management systems”, in *Advanced Learning Technologies (ICALT), 2010 IEEE 10th International Conference on,* pp. 30-34, IEEE, 2010.

[28] C. A. Jara, F. A. Candelas, F. Torres, S. Dormido, F. Esquembre, O. Reinoso, “Real-time collaboration of virtual laboratories through the internet”, *Computers & Education*, vol. 52, no. 1, pp. 126 – 140, 2009.

[29] P. Zervas, A. Kalamatianos, E. Tsourlidaki, S. Sotiriou, D. G. Sampson, “A methodology for organizing virtual and remote laboratories”, in *Digital systems for open access to formal and informal learning*, pp. 235-255, Springer International Publishing, 2014.