Current Status of Online Science and Engineering Education

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Abstract-- **Online education has grown considerably over the past two decades thanks to the tremendous progress in communication technologies, particularly the Internet, and their affordability. Many online colleges and universities as well as online programs have been created at an increasing rate. Online education offers many attractive advantages including the potential for making college education more flexible, affordable and accessible across the world. Even many of the established traditional onsite colleges and universities have been steadily introducing an increasing number of online courses. The sciences and engineering disciplines, especially at the undergraduate level, are however conspicuously lagging. Many experts think that this is mostly due to the difficulty of providing hands-on laboratory experiments online. In addition, currently available online tools in science are very limited in number and scope. Educators at the forefront of online education have tried various methods to remedy to this problem with some success. Even though considerable progress has been made in this area, a lot remains to be done. On the other hand, the need to develop online science and engineering programs is both pressing and crucial. In this paper, existing methods of teaching laboratory experiments online are reviewed. Using an overall cross-curricular systems analysis, the current difficulties and the conditions required for effective and viable science and engineering online programs are discussed.**

***Index Terms*— home kits, online education in science and engineering, online lab experiments, simulations.**

I. INTRODUCTION

Online education, also called e-learning or distance education, has been gaining widespread use for the past two decades [1-4, 16]. Continuous advances in Internet-related technologies have helped make this possible. Online education provides an enormous potential for an affordable education that overcomes geographical barriers at the national and international level. Basically, it provides a solution for many of the major obstacles that potential students face with traditional colleges and universities, which are mainly time and location flexibility. This flexibility makes it possible for students, including those with full-time jobs, to make their learning process fit within their busy daily work schedule, and take classes and earn degrees at distant colleges and universities without having to change location. These features of online education make it especially attractive for the adult professionals who are more constrained in time and space. By making it easier for the adult population to further their education, industry, the economy, and society as a whole will clearly benefit significantly. Other beneficial aspects of online education include the empowerment of the student, becoming more of an active learner [1-4, 16], while being mentored remotely by the instructor. There is a general consensus among educators that active student-centered learning is highly effective.

One of the major objectives and challenges of online education is to be able deliver the same level of education and programs as traditional onsite schools. In other words, the change in methods of delivery should not adversely affect the knowledge and skills gained and the educational programs delivered should fulfill the same generally accepted and required learning objectives as established by accrediting organizations. Graduates from online schools should have an equal footing with those from traditional schools on the job market and in their workplace. Whereas onsite schools use the same delivery method no matter what the discipline or program is, online education presents more challenges in the experimental sciences (physics, chemistry, engineering, etc.), which generally require laboratory experiments, than in the social sciences.

A quick snapshot of currently offered online education programs shows a huge preponderance of courses and degree programs in the social sciences such as literature, criminal justice, administration, and management, compared to the experimental sciences. Most early startup schools in the online world consisted mainly of programs and degrees in the first category, which is easily explained by the fact that these fields require only the delivery of text and video lectures that are easily delivered synchronously or asynchronously through the Internet. This made it easy for traditional onsite schools to offer their existing courses through the online environment and for new schools to create new courses in various fields and deliver them online. Onsite schools can also offer hybrid programs where students can combine traditional onsite and online courses toward their degree. Experimental sciences are more challenging because of the need and requirement to accompany lectures with laboratory experiments where students acquire the skills and ability to experimentally apply theoretical concepts to verify the validity of physical laws and principles, and mathematical models.

Laboratory experiments pose more challenges because of the need for students to have access to instrumentation and to physically manipulate them. Several schools have successfully accomplished this task, some even specifically focusing on science and engineering programs [30]. There are four main methods through which laboratory experiments are delivered and all of them have been successfully used. These four methods are (1) online simulations where physical phenomena are modeled using software tools; (2) laboratory home kits that students use in their homes or place of work to run pre-designed experiments; (3) remote labs where students remotely access a distant physical laboratory to "perform" experiments by manipulating virtual instruments through a computer interface; and (4) residential labs which are brick and mortar laboratories located at an onsite school where students spend a certain amount of time during the semester to perform all their experiments at once. By their very nature, some of the above-mentioned methods cannot fully replicate a traditional laboratory setting.

One of the advantages of regular onsite laboratory experiments is the fact that they are supervised by an instructor or supervisor and provide an interactive environment where students can get help and guidance with setting up and performing experiments. In some areas, such as chemistry, safety issues add another layer of complexity because of the risks inherent to handling chemical substances. Whereas in regular onsite laboratories the teacher and/or supervisor monitors if safety guidelines are adhered to, it would be hard or impossible to ensure a similar situation in a student's home when using home kits for chemistry. Therefore, home kits should be carefully designed with all these safety issues taken into consideration.

This paper discusses the current state of online science and engineering education and the different possibilities of delivering laboratory experience online. In section 2, the current and past experience with online science and engineering education is summarized. Section 3 discusses the pros and cons of online delivery of laboratory experiments, the role of simulations, hands-on laboratory experiments using home kits, remote labs, and residential labs. It concludes with some suggestions on the optimal method of delivering laboratory experience in online science and engineering education.

II. CURRENT STATE OF ONLINE SCIENCE AND ENGINEERING EDUCATION

There is a general agreement among science and engineering educators that a major, if not the main, challenge for online science and engineering education is the difficulty of providing hands-on laboratory experience in science and engineering courses [5-36]. In a well-researched and comprehensive paper, Bourne *et al.* [5] provided an extensive overview of online engineering education and pointed out that laboratory experiments were a major challenge. From our experience and the published literature [1-34] this could be a major reason most science and engineering faculty as well as administrators at traditional colleges and universities "shy" away from online education [1-4].

Bourne *et al.* [5] also provided a comprehensive analysis indicating that most growth in online engineering education is at the Master's degree level. They pointed out that this is most likely due to the shorter duration of the Master's program and the fact that laboratory experiments, at least hands-on laboratory experiments, are not generally needed in Master's programs even when offered onsite, since Master-level students already have an undergraduate science or engineering BS degree and, therefore, are expected to have developed the required laboratory skills. The difficulty of providing online laboratory experience is well summarized by Boschmann of Indiana University - Purdue University, Indianapolis [6], who states that "most current distance education courses are non-science in order to avoid the difficult issue of laboratories. No other aspect has caused a greater challenge than the delivery of laboratory experiments via online education."

Feisel *et al*. performed an extensive and well-researched study in 2005 on the role of laboratory experimentation in engineering [7]. They provided a detailed analysis of the evolution of laboratory experiments in engineering. They concluded that historically laboratory experiments were of course a fundamental part of the engineering curriculum but were overlooked and almost "taken for granted" after World War II because of the emphasis in that period on engineering science and theory. They found that this led to growing complaints in industry regarding the lack of laboratory skills on the part of engineering college graduates [7].

To help resolve this issue, the American Board for Engineering and Technology (ABET), which provides accreditation to engineering and technology programs, convened a colloquy in January 2002 with the support of the Sloan Consortium [5] where a team of fifty distinguished engineering educators, with experience in the development and teaching of engineering laboratory experiments, gathered to discuss and define the fundamental objectives of engineering instructional laboratories. Those objectives would apply to any method of instructional delivery [8, 9]. It was found at the colloquy that, surprisingly, there was no clear and common definition among engineering educators of what exactly the objectives of laboratory experimentation are. So the teaching of laboratory experience online could not even be addressed without first defining what those objectives are for onsite laboratory experiments.

Feisel *et al*. [7] rightly pointed out that no assessment or improvement could be made without establishing clear and specific objectives that all schools can adhere to. As a result, the participants at the colloquy came up with 13 learning objectives for the laboratory experience in engineering applicable to the entire undergraduate program. The objectives are listed below [7-9]. Each objective starts with the following: "By completing the laboratories in the engineering undergraduate curriculum, you will be able to…."

1- *Instrumentation:* Apply appropriate sensors, instrumentation, and/or software tools to make measurements of physical quantities.

2- *Models:* Identify the strengths and limitations of theoretical models as predictors of real world behaviors. This may include evaluating whether a theory adequately describes a physical event and establishing or validating a relationship between measured data and underlying physical principles.

3- *Experiment:* Devise an experimental approach, specify appropriate equipment and procedures, implement these procedures, and interpret the resulting data to characterize an engineering material, component, or system.

4- *Data Analysis:* Demonstrate the ability to collect, analyze, and interpret data, and to form and support conclusions. Make order of magnitude judgments, and know measurement unit systems and conversions.

5- *Design:* Design, build, or assemble a part, product, or system, including using specific methodologies, equipment, or materials; meeting client requirements; developing system specifications from requirements; and testing and debugging a prototype, system, or process using appropriate tools to satisfy requirements.

6- *Learn from Failure* Recognize unsuccessful outcomes due to faulty equipment, parts, code, construction, process, or design, and then re-engineer effective solutions.

7- *Creativity: D*emonstrate appropriate levels of independent thought, creativity, and capability in real-world problem solving.

8- *Psychomotor:* Demonstrate competence in selection, modification, and operation of appropriate engineering tools and resources.

9- *Safety:* Recognize health, safety, and environmental issues related to technological processes and activities, and deal with them responsibly.

10- *Communication:* Communicate effectively about laboratory work with a specific audience, both orally and in writing, at levels ranging from executive summaries to comprehensive technical reports.

11- *Teamwork:* Work effectively in teams, including structure individual and joint accountability; assign roles, responsibilities, and tasks; monitor progress; meet deadlines; and integrate individual contributions into a final deliverable.

12- *Ethics in the Lab:* Behave with highest ethical standards, including reporting information objectively and interacting with integrity.

13- *Sensory Awareness:* Use the human senses to gather information and to make sound engineering judgments in formulating conclusions about real-world problems.

As pointed out by Feisel *et al.* [7], these objectives do not necessarily represent a national consensus. However, they could be reliably taken as a solid foundation as to the role of laboratory experiments in engineering. We believe that the formulation of the above objectives is a milestone and we may adopt this definition of the objectives. In addition, ABET's involvement in the definition of these objectives is significant in that it clarifies its overall expectations regarding laboratory experience for the purpose of accreditation [10].

A. Laboratory Experimentation and the Scientific Method in Science and Engineering

At this point it is worthwhile looking back at the relation of engineering toward other sciences. Engineering undergraduate programs typically require two or three courses of calculus-based general physics in the freshman and sophomore years. One may define engineering as an applied physical or life science. In reality, engineering is more multidisciplinary involving aspects of marketing, business, finance, law, ethics, etc. The goal of an engineer is to apply relevant physical laws to design the most affordable quality systems that satisfy societal needs. Among all science disciplines, physics clearly plays the central and foundational role in the education of an engineer. Science is based on the scientific method where experiments play a fundamental role.

The scientific method is at the foundation of physics. It is based on an iterative process involving observation-hypothesis, theory formulation, experimentation, analysis, and validation through repeat testing. This cyclic process is illustrated in the in Fig. 1 [11].

Engineering students first learn the scientific method primarily in their required general physics courses. Typically, these calculus-based courses cover all areas of general physics (mechanics, thermodynamics, sound waves, electromagnetics, optics, modern physics). In their real-life projects, engineers must design a system that satisfies many technical, social, and financial constraints. They start with the physical system, develop a physical model, from which they abstract a mathematical model based on the physical laws. Then they "virtually" experiment or test the model through simulations. If the behavior is as predicted, they proceed to the real-life physical test in which they must design and perform experiments and analyze data as they have learned in the general physics labs. This process is illustrated in Fig. 2 [12].

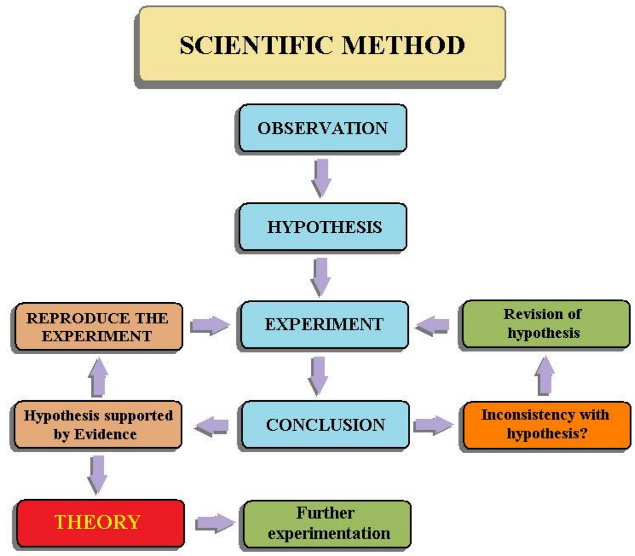

Figure 1: Flow diagram for the scientific method [11].

In physics, as well as in engineering, the scientific method "approximates" or idealizes the real world through models that are then validated and verified through experiments. In physics, the model takes the form of physical laws. This is a very important fact scientists and engineers must be aware of and trained to deal with. Traditionally, engineers first acquire these fundamental skills in their general physics classes and learn about the importance of and how to perform data and error analysis and modeling, and the limitations of the models. We believe that a solid preparation in the physics laboratory experiments should be an important requirement for an effective online engineering education in which the ABET learning objectives, especially objective 2, are rigorously fulfilled. Only objective 5 (design) is not covered in the general physics pre-requisite courses.

One of the authors (S. Badjou) has had a long experience teaching calculus-based general physics labs that are required of engineering and science majors at Northeastern University, Boston, Massachusetts. Students are given a carefully written laboratory manual including experiments covering all areas of physics. For each experiment, a detailed handout is provided that includes the objectives, theory, equipment, procedure, analysis, conclusions, and questions. This can serve as a model for students to develop their own laboratory experiments in subsequent courses. This experience leads us to believe that a set of carefully designed and taught laboratory experiments in the two or three prerequisite courses of general physics could provide the required skills in scientific experimentation for engineering students. Students will then further apply these skills in subsequent engineering laboratory experiments and projects.

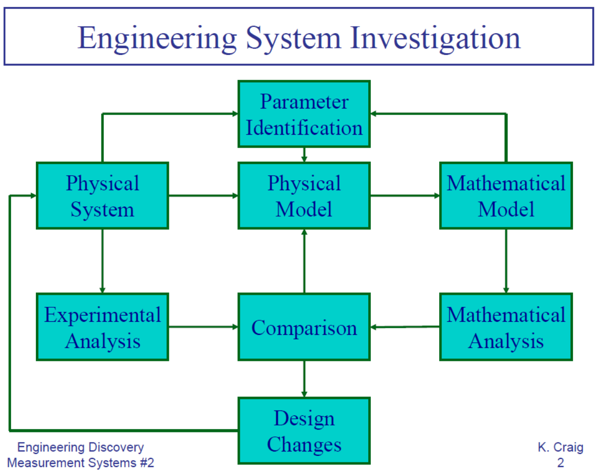

Figure 2. Steps involved in engineering design [12].

Because all laboratory skills are first developed in the calculus-based general physics courses required of engineering students, one should take a systems approach to the issue of teaching both science and engineering laboratory experience online. One cannot resolve the issue of teaching online engineering separately from that of teaching the sciences online, especially given the fact that they face the same basic issues and all the fundamental laboratory experimentation objectives identified by ABET, except objective 5 (design), are first provided in the general physics prerequisites in engineering curricula.

B. Methods of Laboratory Experiments in Online Education

Online education in science and engineering has to adhere to the same objectives and requirements as at the traditional onsite colleges and universities [19]. This includes the necessity for teaching laboratory experiments online. To overcome the difficulty of performing physical experiments from a distance and teach all the necessary laboratory skills, four methods of teaching science and engineering laboratory experiments online have been used [5-36], and are discussed in this section.

Simulations

Simulations are based on physical laws implemented in software to predict desired physical properties, such as voltage, stress and strain, electric and magnetic fields, etc.. They are an important and necessary part of modern engineering design as discussed above. They are based on proprietary or open-source software. Popular simulation software in the US include LabVIEW, Matlab/Simulink, Java Applet, Flash [22]. Simulations have many advantages, including [19, 22]:

- Low cost especially with the use of open-source software. Proprietary software such as LabVIEW and Matlab/Simulink provide affordable student versions as well as institution licenses.
- May substitute for experiments that require expensive equipment, are unsafe, hard, or impossible to perform physically.
- Do not require physical infrastructure and may be done on a PC or laptop.
- Permit unlimited repetitions under different conditions with the proper selection of parameters.
- Allow unlimited safe failures.
- Allow students to learn from failures.
- Reinforce conceptual understanding.
- Allow 3D visualization of animations and processes that are otherwise hard, unsafe, or impossible to perform physically. This is especially important in biology and bioengineering, in visualizing electromagnetic waves, stress, heat transfer, fluid dynamics etc..

Remote Labs

It appears from our literature search that most engineering educators have experimented with remote labs. Many seem to think that this is the most desirable option for online laboratory experiments [5, 36]. Balamuralithara *et al.* [19] carried out an extensive study of physical laboratories, simulations, and online remote labs and made a comparison according to cost, accessibility, hands-on experience, etc.. Their findings indicate that remote labs are costly [19]. Some educators propose that educational institutions share remote labs to reduce the costs [19, 21, 22, 36]. In addition, access to remote labs, like real onsite laboratories, is limited, and remotely controlling onsite experiments is not equivalent to real-life physical experiments because the student does not physically interact with the instrumentation. One can safely conclude that online simulations and remote labs by themselves do not, and cannot, satisfy all 13 ABET laboratory experience objectives discussed earlier.

Home kits

Home kits are used to perform real experiments at home. These are either loaned or sold to the students. A video for demonstration and a manual may be supplied. Because the student experiments on his/her own in the absence of an instructor or teaching assistant, home kit experiments must be carefully designed to be safe. Home kits have been tried and assessed, especially in the sciences, with consistent success.

Our research in the literature has revealed that home kits appear to have been most used and favored in the sciences. In engineering, by contrast, they appear to have been largely neglected. This may be attributed to the fact that the basic focus of an engineer is design, even though ABET objective 2 is clearly related to the scientific method.

Jeschofnig [26, 27] reports that "some educational institutions compile lists of rationales and objectives for requiring laboratory components to accompany campus-based science courses, and that it is reasonable to follow the same standards for laboratory experience in distance learning. These include:

- Students learn by doing.
- Experimentation must teach basic laboratory techniques.
- Experimentation demonstrates and reinforces understanding of the scientific method.
- Experimentation must teach the ability to adhere to instructions on laboratory safety, to recognize hazardous situations and to act appropriately.
- Students must develop scientific manipulative skills in performing quantitative experiments.
- Students must measure, manipulate, observe, and reason.
- Students must learn to observe, recognize, and interpret patterns in their laboratory activities.
- Experimentation should help students learn to manipulate and interpret numerical data.
- Students need to develop the ability to keep careful records of experimental observations and to communicate with others about these observations and the conclusions drawn from them.
- Experimentation should teach the ability to work independently; and to work effectively as part of a team.
- Experimentation should show the relationship between experimental measurement and chemical or scientific theory."

Comparing the above list to the 13 ABET laboratory experience objectives, it is clear that they are similar except for objective 5 (design). Reporting on his ten-year experience teaching physics and chemistry using home kits, Jeschofnig [26, 27] lists the various advantages of home kit. Following a careful assessment of teaching chemistry on campus and using home kits, he concludes that "Student learning in distance learning science courses with home-based lab kits is at least equivalent to and usually a little better than in face-to-face courses with a campus based lab" [27].

Kennepohl and Shaw of Athabasca University in Canada gathered a diverse body of experts on online science education who wrote on their experiences and produced an excellent synthesis of the results to date in a seminal book published in 2010 titled *Accessible elements: Teaching Science Online and at a Distance* [30]. The book is especially valuable as it includes a wide cross section of multidisciplinary fields, which provides a badly needed integration of experiences and takes a systems view of the problem, thereby suggesting efficient cross-discipline solutions. As noted by the editors, the basic issues faced by individual educators in their respective scientific fields are similar to those in engineering.

In his foreword to the book, Professor Michael Moore of The Pennsylvania State University, editor of *The American Journal of Distance Education*, summarizes the evolution of the teaching of science laboratory experiments in distance education and reports on the successful experience with home kits at the Open University, UK [30].

Jennings [28] reports a successful implementation of home kits all the way to third-year-level physics in online teaching at Murdoch University, Australia. He reports that inexpensive kits and, in some cases, real data obtained from complex experiments sent by the university are successfully used off-campus by their students.

Al-Shamali *et al*. of Athabasca University [25] report on their positive experience using home kits. They argue that experimentation does not have to take place at an especially equipped traditional laboratory using the available equipment there as has been traditionally done. They have designed home laboratory experiments for their physics students using low-cost materials and household items, and the quality of the results exceeded their expectations. They report a dramatic increase in student participation rates.

Shaw *et al*. of Athabasca University performed a comprehensive analysis on the relative cost of distance learning teaching of science laboratory experiments [15]. Defining "opportunity cost [as] the sum total of the costs of time, travel, and other inconveniences that students must incur during the course," they point out that "in science courses, the laboratory component is often the most expensive in terms of opportunity cost for students." They concluded that both distance learning providers and students in general chemistry greatly benefited from home kits in terms of cost, and that can also be the case for students in physics and geology because home kits can be made affordable.

Blended/residential labs

Several institutions have experimented with the blended or hybrid approach using residential labs [5, 20, 30]. Students gather for a week or on some weekends on campus at a local college, university, or high school to perform all required laboratory experiments. This method has the merit of satisfying all 13 ABET laboratory experience objectives. However, there are many disadvantages including the requirement for the student's presence on campus, which is contrary to the spirit of distance education, and associated costs. Another disadvantage is the lack of synchronization between laboratory experiments and lectures. Blended labs also require a lengthy absence from work which will be costly for employers [13]. It could be suitable for nearby locations but not for remote places such as distant cities or different countries. Compared to home kits, they are less cost-effective as they require the same infrastructure and equipment as onsite laboratories and entail additional costs.

A number of institutions have experimented with a mix of various methods of teaching laboratory experience. For example Palmer *et al*. [35] experimented with "the flexible approach" at Deakin University, Australia, where a mix of different methods is used for every particular situation including individual arrangements where a student can elect to use an experimental facility at work or a local institution.

III. DISCUSSION

Educators in online science and engineering programs have experimented with the following methods to deliver laboratory experience: simulations, home kits, remote labs, and blended labs. Some educators and institutions have also experimented with a mix of some or all four methods. By their very nature, simulations are the most suitable to provide online experiments using any of the available software tools. However, they do not fulfill all 13 ABET laboratory experience objectives, especially objectives 2 and 13, where direct experimentation with the physical world is required. Simulations are an important part of modern engineering design. In a way, they may be considered as the first step in testing a model since in engineering it is always more cost-effective and efficient to start with virtual experiments (simulation) followed by a physical experiment. Therefore, in their design courses, engineering students must use both simulations and physical experiments in order to validate and verify their mathematical models.

Home kits have been tried in physics, chemistry, biology, and earth sciences [25-33] and have been found to be both effective and affordable. Experiments that require more costly equipment as found at onsite schools cannot be performed with this method. Some authors have found this method to be best suited for adults as they are more independent learners [29]. In the course of our review of the literature, we found that most engineering educators do not seem to consider home kits a desirable solution. It appears that many of them prefer to keep existing onsite equipment and experimental setups and have students access the equipment remotely [36].

Home kits in both science and engineering must be designed with the necessary safety guidelines because they are intended to be used without instructor supervision. Onsite laboratory experiments must also be designed for safety because, in addition to hurting students, unsafe experimental setups may also result in legal liabilities. However, the requirement for safety is even more important for home kits and many authors are of the opinion that safety is a major issue [6].

Remote labs have been tried by many educators [17-24, 34, 36] especially in engineering. They satisfy many, but not all, of the 13 ABET laboratory experience objectives that are provided by hands-on and home kit experiments. This method is quite costly and therefore requires some form of partnerships [19,36]. We believe this method may be suitable for some advanced engineering classes and in research projects. This method is also appropriate when the equipment is costly, thereby complementing the take-home kits method.

Blended labs seem to satisfy all 13 ABET laboratory experience objectives. One disadvantage is the requirement for onsite presence that negates the main advantage of online education, and may not be implemented for students who are located in distant locations such as across continents. However, we believe it provides a compromise, when practical. Blended labs are also not as cost-effective as home kit experiments.

IV. CONCLUSIONS

From our extensive research, it is clear that online education has gained lots of ground in higher education and continues to grow [1-4]. However, science and engineering are lagging behind all other disciplines [5, 6]. Various studies have indicated that the difficulty of offering hands-on laboratory experience that satisfies the set of 13 ABET laboratory experience objectives for engineering that have been formulated by ABET is the major challenge. The physical and life sciences face the same difficulties as engineering regarding the delivery of laboratory experience in online education [25-36].

The issue of teaching science and engineering laboratory experiments online involves the search of an optimal solution that will satisfy all 13 objectives identified by ABET, although science laboratory experiments do not have to satisfy objective 5 (design). A systems approach must be followed throughout the duration of the undergraduate program. The optimal solution may be defined as one that satisfies relevant objectives while minimizing the cost for the student, education institution, and employers since a sizable proportion will be adult learners, and offers as much time and location flexibility as possible. In a recent study by the National Academy of Engineering (NAE) titled *Lifelong Learning Imperative in Engineering: Sustaining American Competitiveness in the 21st Century* [13], it was found that the cost for the employer was a major impediment for the enrollment of adult learners in continuing education programs. The advantage of a systems approach is that it effectively, at once, solves the issue of teaching science and engineering online.

In light of the vast experimental evidence from various schools and programs and the points discussed in this paper, we believe that the optimal solution for online science and engineering education must be one that satisfies all 13 ABET objectives (minus objective 5 for science) upon completion of the degree. One such solution could be to use a mix of the four methods depending on the circumstances. To our best knowledge, the present paper is the first to discuss the issues of online science and engineering education in an integrated way.

REFERENCES

[1] I. E. Allen and J. Seaman, "Learning on demand online education in the United States," *Babson College, The Sloan Consortium*, January 2010.

[2] I. E. Allen and J. Seaman, "Changing course: ten years of tracking online education in the United States," *Babson Survey Research Group,* January 2013.

[3] U.S. Department of Education, Office of Planning, Evaluation, and Policy Development, "Evaluation of Evidence-Based Practices in Online Learning: A Meta-Analysis and Review of Online Learning Studies," Washington, D.C., 2010.

[4] I. E. Allen and J. Seaman, "Going the distance online education in the United States," *Babson Survey Research Group, Babson College*, November 2011.

[5] J. Bourne, D. Harris, and F. Mayadas, "Online engineering education: Learning anywhere, anytime," *Journal of Online Education,* January 2005.

[6] E. Boschmann, "Institutional Considerations: A Vision for Distance Education," in *Accessible Elements*, AU Press, Athabasca University, 2010.

[7] L. D. Feisel and A. J. Rosa, "The Role of the laboratory in undergraduate engineering education," *Journal of Engineering Education*, January 2005.

[8] G. D. Peterson and L.D. Feisel, "e-Learning: The Challenge for Engineering Education," in *e-Technologies in Engineering Education, A United Engineering Foundation Conference*, Davos, Switzerland, 11–16 August 2002.

[9] L. D. Feisel and G. D. Peterson, "A Colloquy on Learning Objectives For Engineering Education Laboratories," in *Proceedings of the 2002 American Society for Engineering Education Annual Conference & Exposition*, 2002 .

[10] Criteria for Accrediting Engineering Programs, 2012 – 2013 http://www.abet.org/DisplayTemplates/DocsHandbook.aspx?id=3143.

[11] The scientific method: http://www.conservapedia.com/Scientific_method

[12] K. Craig, "Modeling, Computing, & Measurement: Measurement Systems #2," Rensselaer Polytechnic Institute, ftp://ftp.ni.com/pub/devzone/tut/measurementsystems5.pdf

[13] S. R. Singer, N. R. Nielsen, and H. A. Schweingruber, Eds, National Research Council. (2012). *Discipline-Based Education Research: Understanding and Improving Learning in Undergraduate Science and Engineering*. Committee on the Status, Contributions, and Future Directions of Discipline-Based Education Research. Board on Science Education, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

[14] A Mayadas et al., "Online education today," *Science* 323: pp. 85–89, January 2009.

[15] L. Shaw and R. Carmichael, "Needs, Costs, and Accessibility of Distance Learning Science Lab Programs" in *Accessible Elements* , AU Press, Athabasca University, 2010.

[16] National Science Board, "Science and Engineering Indicators 2012," Arlington VA: National Science Foundation (NSB 12-01), 2012.

[17] J. O. Campbell et al., "Cost-effective distributed learning with electronics labs," *JALN* Volume 8, Issue 3 — June 2004.

[18] M. Cooper, and J. M. M Ferreira, "Remote laboratories extending access to science and engineering curricular," *IEEE Transactions on Learning Technologies*, 2(4), pp. 342–353, 2009.

[19] B. Balamuralithara and P. C. Woods, "Virtual laboratories in engineering education: the simulation lab and remote lab," Multimedia University, 63100 Cyberjaya, Malaysia *Computer Applications in Engineering Education* Volume 17, Issue 1, Article first published online: 28 AUG 2008.

[20] V. Mahesh and C. Woll, "Blended learning in high tech manufacturing: a case study of cost benefits and production efficiency," *Journal of Asynchronous Learning Networks* 11(2), pp. 43-60, July 2007.

[21] J. Trevelyan, "Lessons learned from 10 years experience with remote laboratories," *International Conference on Engineering Education and Research,* Progress Through Partnership, Ostrava, Czech Republic, 2004, ISSN 1562-3580.

[22] X. Chen, G. Song, and Y. Zhang, "Virtual and remote laboratory development: A review," *Earth and Space* 2010: Engineering, Science, Construction, and Operations in Challenging Environments.

[23] D. Lowe et al., "LabShare: Towards a national approach to laboratory sharing," *20th Australasian Association for Engineering Education Conference University of Adelaide*, 6-9 December 2009.

[24] D.A. Cancilla and S.P. Albon, "Reflections from the moving the laboratory online workshops: emerging themes," *Journal of Asynchronous Learning Networks* 12(3-4), pp. 53-59, December 2008.

[25] F. Al-Shamali and M. Connors, "Low-cost physics home laboratory," in *Accessible Elements*, AU Press, Athabasca University, 2010.

[26] P. Jeschofnig, "Effective laboratory experiences for distance learning science courses with self-contained laboratory kits," *Proceedings of the 20th Annual Conference on Distance Teaching & Learning* (2004).

[27] P. Jeschofnig, "The evolution of distance Science lab options and current practices," *Colorado Mountain College*, April 2007.

[28] P. Jennings, "An external physics degree," in *Snapshots — Good learning and teaching in physics in Australian universities*, Mendez, A. et al. (Eds.), December, 20, 2005.

[29] R. Lyall and A. F. Patti, "Taking the chemistry experience home —home experiments or "kitchen chemistry", in *Accessible Elements*, AU Press, Athabasca University, 2010.

[30] D. Kennepohl and L. Shaw, Eds., "Accessible Elements: Teaching science online and at a distance," AU Press, Athabasca University, 2010.

[31] D. Kennepohl, "Microscaled laboratories for home study: a Canadian solution," *Chemeda: The Australian Journal of Chemical Education*, *54/55/56*, pp. 25–31, 2000.

[32] D. Kennepohl, "Home-study microlabs," *Journal of Chemical Education,* Vol. 73 No. 10 October 1996.

[33] D. Kennepohl, "Using home-laboratory kits to teach general chemistry," *Chemistry Education Research and Practice,* 8, 337–346, 2007.

[34] D, Kennepohl, J. Baran, M. Connors, K. Quigley, and R. Currie, "Remote access to instrumental analysis for distance education in science," *Int. Rev. Res. Open Distance Learn.* 6, 2005.

[35] S. Palmer, D. Holt, and A. Farley, "Toward New Models of Flexible Education to Enhance Quality in Australian Higher Education," in *Accessible Elements*, AU Press, Athabasca University, 2010.

[36] D. Kennepohl, "Remote Control Teaching Laboratories and Practicals," in *Accessible Elements* , AU Press, Athabasca University, 2010.

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