

## **A Systems Engineering Framework for Online Course Design and Delivery**

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## **ABSTRACT**

This paper introduces a systems engineering-based framework to assist in online engineering education. Specifically, the framework is intended to provide a structured methodology for the development of a fully online course, either brand new or modified from an existing face to face course. The main strength systems engineering provides to online engineering education is the holistic worldview and the life-cycle approach. Adopting the life-cycle approach to online engineering education facilitates in a smooth transition for faculty members and departments who are in the process of modifying their curriculum to meet the demands from students and the industry. The paper concludes with a discussion of implications of the framework for online engineering education and future research opportunities.

## **1 INTRODUCTION**

Online education and learning has established itself as an independent discipline, due to the increasing demand from academia and practice alike. Universities more and more offer either blended or fully online courses and fully online degrees. The flexibility of online education is especially appealing to working, professional adult students. Even though the data is scarce on the national profile of online students and their demographics, Mayadas, Bourne and Bacsich (2009) state that working adults are indeed the target population of online classes. The 2008 Sloan Consortium survey of online education reports that more than 20% of all students in U.S. Colleges enroll in at least one online class. Academic research on the effectiveness and efficiency of online education is now published in journals solely dedicated for this topic, such as Journal of Asynchronous Learning Networks, American Journal of Distance Education, Quarterly Review of Distance Education and Journal of Online Learning and Teaching, among others.

The recent announcement from the White House of the launch of *Change the Equation* initiative, a public-private partnership that is designed to increase literacy in Science, Technology, Engineering and Math (STEM), shows the level of importance STEM education has on society. The three goals this initiative works towards are 1) Great Teaching, 2) Inspired Learners, and 3) A Committed Nation (Change the Equation website). One of the ways to improve teaching and learning within STEM is to increase the availability of degree programs. Degree-awarding institutions are moving towards more flexible and advanced course delivery technologies in order to reach broader student populations.

## **2 CURRENT STATE OF ONLINE ENGINEERING EDUCATION**

For the past ten years, traditional face-to-face classroom education has had a strong competitor in the form of online education (OE). Together with this new approach, the non-traditional classroom experience has been transformed into an alternative delivery medium. Almost twice monthly, *The Chronicle of Higher Education* publishes articles about and discusses news of the state of online education.

A survey conducted by the *Instructional Technology Council* (2008) on the impact of eLearning at Community Colleges reports that there has been an 11.3 percent increase in the distance

education enrollment between Fall 2006 and Fall 2007. The seventh annual Sloan Survey of Online Learning (2009) states that 73% of the institutions they surveyed (more than 2500 colleges and universities) reported an increased demand for *existing* online courses and programs, and 66% of institutions reported increased demand for *new* courses and programs. In the same survey, it is reported that the demand for online offering is greater than that for the corresponding face-to-face offerings, and that 1 out of 4 higher education student has at least taken one online class.

According to the data provided by American Society of Engineering Education in 2009, bachelor's degrees in engineering remain unchanged since the previous year. A close look at the engineering disciplines, however, show that fields related to energy have grown 150% since 2003. The report also shows that Master's degrees in engineering has grown 38% over the past ten years. Doctoral degrees, similar to Bachelor's, have been stable over the past three years. When considering that the target population of online degrees is working professional students, the growth of the Master's degrees awarded becomes the main source that is in focus, since there is a high probability that professional students to complete their Master's degrees will not continue to a Doctoral program; the academic route will not be within their interests.

With current trend moving towards online education, particular attention needs to be paid to the issue of quality. According to a study conducted by Hirumi (2005), there are two distinct approaches to quality of e-learning: educational, or industrial. In other words, guidelines can be defined for programs and courses, measuring quality in terms of effectiveness and efficiency; or guidelines can be defined in terms of learners and learning objectives and quality is then measured in terms of increasing learner achievement and satisfaction. The mere fact that there is a distinction between educational and industrial perspectives to quality is enough to necessitate the need for standards and guidelines on how online courses could be designed and delivered.

The issue of quality was also discussed by Smith and Mitry (2008) who concluded that if university administrators do not remain committed to high academic standards, e-learning will never reach its true potential. With the increasing number of for-profit institutions who offer online degrees with the support of part-time instructors who may not always have the necessary terminal degrees from accredited universities (Smith and Mitry, 2008), it is crucial that truly academic institutions have to pay extra attention to highlight the strengths of online education, while fighting the challenges and limitations of online education.

### **3 SYSTEMS ENGINEERING FRAMEWORK**

The issue of online education within engineering is a complex topic with many stakeholders involved (the faculty, the students, the university and the industry). Concepts and processes from Systems Engineering have been applied to the topic of online education in order to provide a framework that both academicians and practitioners alike could use. Some universities may not have a support structure for the faculty; providing workshops and seminars on efficient and effective online teaching. As Fabry (2009) suggests, the issue of effectively utilizing the features and tools of the design and delivery mediums, such as Blackboard, needs to be addressed by course developers. The SysEF is intended to provide a structured methodology for the

development of a fully online course, either brand new or modified from an existing face to face course.

The rationale behind using systems engineering as a foundation for the framework is based on the main concepts of systems engineering, as identified in Blanchard (2008):

1. *Holistic view*: Looking at the system of interest as a whole, from a top-down approach is necessary and useful to build successful systems. Considering all aspects of online course development and delivery is crucial for effective and efficient online courses.
2. *Life-cycle orientation*: Addressing all stages of successfully developing and implementing a system, starting with conceptual design and ending with phase-out, will also provide support in OE, since online course delivery also has a temporal component, i.e., design of class, starting the class, finishing the class.
3. *Identification of system requirements*: Identifying clear and complete user requirements and establishing traceability to specific system goals is the key for successful systems. The initial design stages become crucial in identifying the requirements. Identifying the requirements of students and the class, establishing requirements for online course development and delivery, and transferring these requirements to conceptual design goals reduces the probability of making errors later on.
4. *Interdisciplinary effort*: Identifying the different components and the interrelationship between these components of the system will require collaboration of different teams. From an OE standpoint, these different disciplines and teams may be the faculty, the administrative personnel and communications and technology personnel, among others.

#### *Systemic View*

The first step in developing the SysEF starts with the identification of the *system*. A system, as defined by International Council on Systems Engineering (INCOSE) is “a combination of interacting elements organized to achieve one or more stated purposes” (INCOSE Handbook, Version 3.2, 2010). A system will have an *input*, which represents the need; an *output*, which represents the system responding to the determined need; *constraints*, which are external variables imposed on the system; and *mechanisms* or *resources* that are required to develop and deploy a successful system (Exhibit 1).

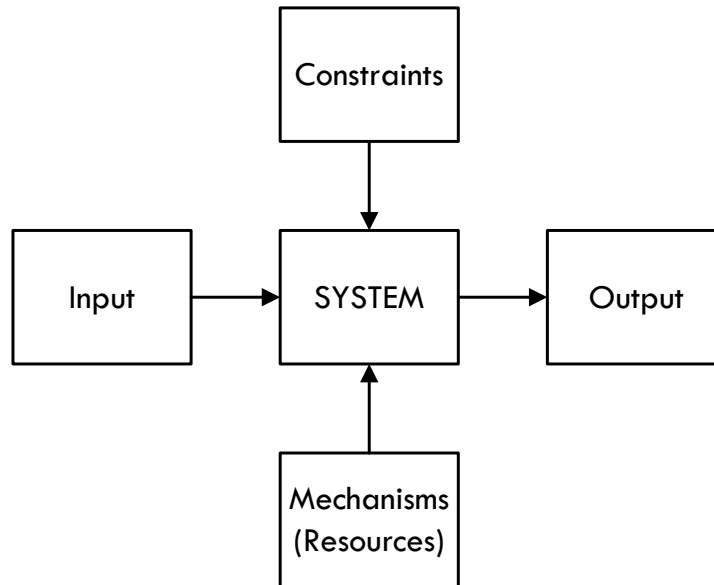


Exhibit 1. The system (from Blanchard, 1998)

One of the general characteristics of any system is that the system consists of a *hierarchy*; for instance, a system is composed of different *subsystems*, these subsystems are composed of different *components*, and these components are composed of different *parts*. All of these different levels of hierarchy add to the complexity of a system, since the items within the hierarchy will also have interrelationships. The concept of hierarchy is also applicable for OE. The main concepts are summarized in Exhibit 2 and explained below:

Key Concepts	Systems Definition	OE Definition
Input	Identification of user requirements; the need	Requirements of the faculty members, the students, the university and the industry
System	A combination of entities that work for a specific purpose	Ex: University, College, Department, Program, Course
Output	A system that will respond to a need in an effective and efficient manner	Ex: An online class, a distance learning center, an online degree

Exhibit 2. System Definitions

- The *policies and procedures* may be university rules and regulations, or accreditation standards that act as constraints. The instructors and the students have to abide by these policies and procedures.
- The *system* that is the focus in this paper is an online course development and delivery system, indicated by Course A.
- The content, administrative, documents, assessment and delivery medium are the *subsystems* that come together to form the system. Each subsystem will consist of different components.
- Content will include topics to be discussed, course modules, learning objectives for each module, and the schedule for the entire semester.

- The Administrative subsystem will include the faculty member’s class policies and procedures, Instructor’s Manual, Test Bank, and other instructor-related materials.
- The Documents will include any document that will be distributed to the students, such as the syllabus, course slides, the textbook and additional reading material (journal papers, magazine articles, etc.).
- Assessment subsystem consists of material that will be used to evaluate the students’ knowledge, such as homework, exams, case studies and group projects.
- Delivery medium is related to the interface that is being used to design and deliver the online class. This could be either WebCT or Blackboard, and will include technical requirements (such as whether the interface works better with Internet Explorer or Mozilla Firefox), student accessibility, and communication channels between the instructor and the student, as well as among students.

Exhibit 3 represents the systemic view of adapting a face-to-face class to an online class.

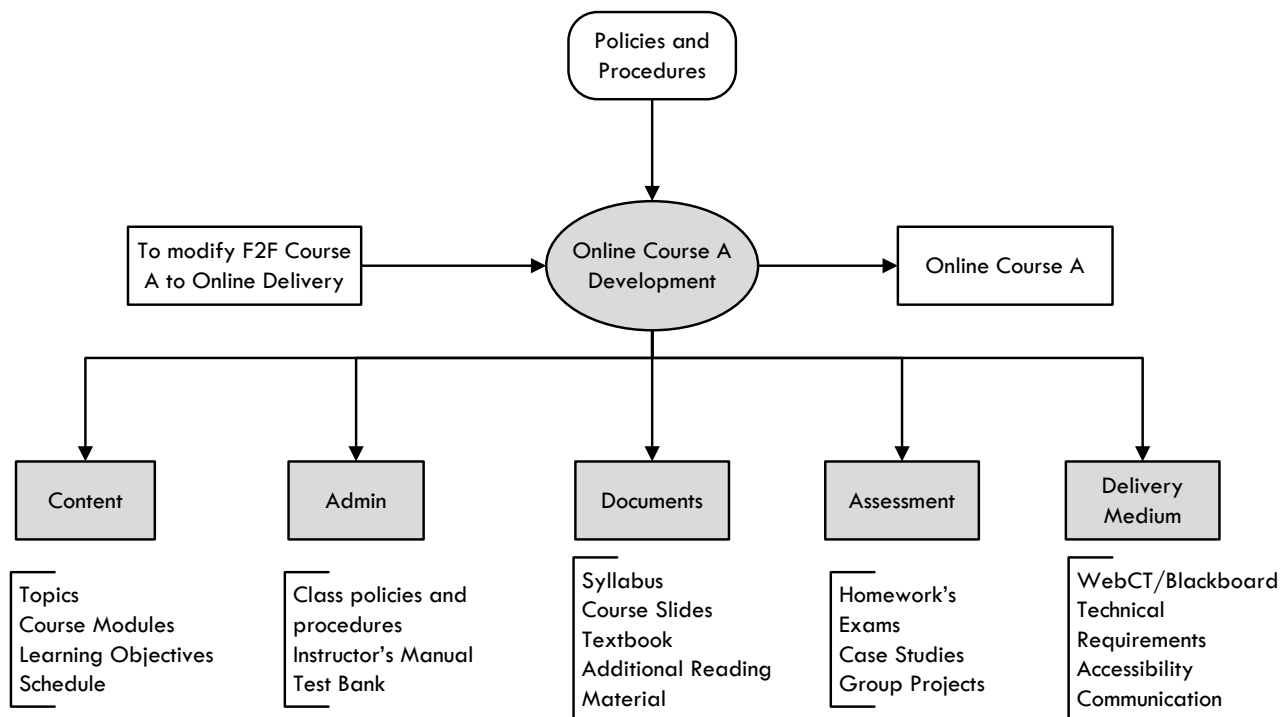


Exhibit 3. *Systemic* view of Online Course Development

### *Life-cycle Orientation*

Once the “systemic view” is established, i.e. the system (and the hierarchy) is described, the life-cycle phases are then identified and discussed. The Systems Engineering Life Cycle (Faulconbridge and Ryan, 2003; Blanchard, 1998) consists of five main phases, bounded by identified need and retirement and phase out from beginning and end, respectively (Exhibit 4).

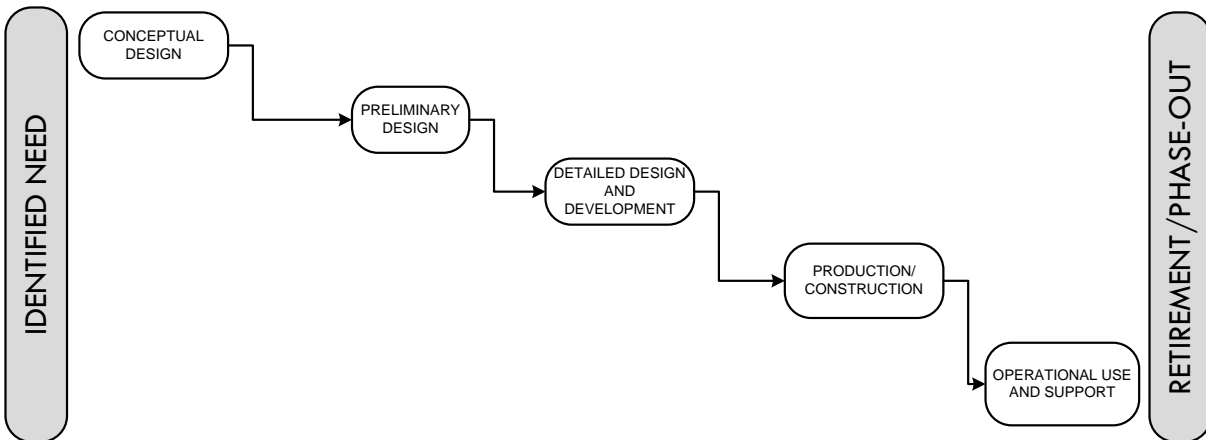


Exhibit 4. Life-cycle approach

The key tasks and elements of each of the phases are described following Faulconbridge and Ryan (2003) and Blanchard (2008). The Conceptual Design stage involves identification of stakeholder requirements, conducting feasibility analysis, conducting requirements analysis, a system-level synthesis and performing a system design review. The Preliminary Design stage involves the subsystem requirements analysis, requirements allocation, interface identification and design, subsystem-level synthesis and preliminary design review. The third stage is Detailed System Design and Development. In this stage, development specifications are revised, detailed requirements for units, assemblies and components are defined, detailed interface requirements for interfaces are identified, product specifications are produced, detailed design of units, assemblies and components are produced, prototypes are built and integrated, and product, material and process specifications are finalized. Once these steps are completed, Production and/or Construction stage is reached. This stage involves production and/or construction of system and components, supplier production activities, system distribution and operation, operational test and evaluation, customer service issues and data collection and analysis for future use. The last stage is, Operational Use and Support, is where the system is put into operation in the “user” environment. Tasks that take place in this stage are logistic support, operational test and evaluation, data collection and analysis, system or subsystem modification if necessary, and customer service activities.

The different phases of the life-cycle can be adapted directly to the design and delivery of an online course:

- *Identify the need:* The need for an online degree program, or a specific course, will be identified through different ways, such as conducting a market analysis, taking into consideration the short and long term goals of the academic institution, demand from industry partners, among others.
- *Conceptual Design:* Once the general need is established, the requirements of different stakeholders have to be identified to proceed with the design of an online course. The stakeholders involved in an online education context will be the students, the faculty, the institution, and the industry. Expectations and requirements of each of these stakeholders have to be identified clearly in order to have a successful online course (Wilkes, Simon and Brooks, 2006). The feasibility analysis will include whether the nature of the course is appropriate to be delivered in an asynchronous, fully online manner. Reuter (2009), for

instance, conducted a research on a science course that had lab and field components, and compared the learning success of online and on-campus students. The results from this study showed that students from both populations met the learning objectives for the course, with online students showing more improvement in variables such as pre- and post- assessments. Despite the highly interactive and applied components of this course, it was designed and delivered as a successful online course. Availability of textbooks, reading material, additional sources, instructor's manual, test banks and any other course material have to be identified in this step. Other policies, such as required technical skills or any prerequisites for the course should also be determined at this initial step. Once it is established that the course and all its components can be adapted to an online course, the design phase can move forward.

- *Preliminary Design:* One of the main components of preliminary design is the identification of the interface. The selection of the course management system and the delivery medium will depend on the policies and procedures of the institution, as well as the availability and appropriateness of the tool chosen to the goals and objectives of the faculty members and the students. Interfaces such as WebCT, Blackboard, Wimba Live Classroom or AdobeConnect have their own advantages and disadvantages, and these may be evaluated through the use of trade-off analysis, a decision matrix or any other tool that allows for multiple objectives. The detailed components of the class, such as the course documents, reading material, assignments and assessments that are aligned with the learning objectives within each module, are determined at this stage.
- *Detailed Design and Development:* Once the course material is near complete, the level of detail required in each of the components starts increasing. For instance, in this phase, for each course module, suggested dates should be selected to give the students an idea on how long they should take to go over the material for that particular module. A list of activities, assignments or assessment that will be linked to each module should be available, as well as how these assignments will be evaluated, in what format any feedback will be given, has to be decided.
- *Production and/or Construction:* In this step, the required readings, course documents, assignments and assessments, the syllabus, course outline, and any other material that will be used by the students and/or the instructor are gathered and the interface that was selected can begin to be populated. At this point, the delivery medium is not being made available for the students yet. The instructor, however, starts to put all the course content onto the interface. The final output of this stage can be considered as a *prototype* of the actual online course. The instructor may also be able to see this medium from the students perspective (by switching off the "edit" mode in Blackboard, for instance) to ensure that the course is easily accessible and can be navigated without any technical or design problems.
- *Operational Use and Support:* The final phase of the lifecycle is where the online course is made available to the student at the beginning of the semester, which means that the system that was designed and developed, i.e. the online course, is now being delivered. One of the main activities of this stage is support, which starts with ensuring that all communication channels between the faculty and the student are open. This also includes the technological support center of the academic institution, where students can get help for any technical problems they may encounter.
- *Retirement and Phase-Out:* The closing of the life-cycle is when the online course is no longer available to the students, which is mostly at the end of the semester. The course may be migrated to the next semester, or may be kept on hiatus until it is offered again. Since a

great amount of information is available online, in order to avoid the loss of information because of any technical glitches or extreme weather-related events, all course content should be stored externally, outside of the intended interface.

### *Support Structure*

Full and successful implementation of these concepts and principles depends on both *technological* and *management* issues, similar to systems engineering (Blanchard, 1998). Without adequate and appropriate people and organizational support, the technological tools and models will not be efficient, or may not be applied successfully. Integration of necessary organizational support is crucial when identifying which specialties are going to be needed when designing, developing and deploying the system. From the technical perspective, computing and communication services, or computing and telecommunications centers within academic institutions will ensure effective and efficient design and delivery of online courses. However, without effective management support, the technical components cannot survive in isolation. The strategic goals, as well as short-term goals and objectives of the institution have to be aligned with the goals of the degree programs, so that they receive organizational and administrative support from their institution. Research shows that OE proves to have a significant effect on budget issues that favors the university. Betts, Hartman and Oxholm (2009) have identified several economic factors that drive the enrollments in online and hybrid programs. Tuition, state funding, financial aid and endowments are among the many factors that impact enrollment in these non-traditional programs. They further state that in order to provide long-term sustainable programs, the colleges and universities should balance academic quality and accountability with online education. However, a report through the Sloan Foundation (The Sloan Survey, 2009) shows that the trend for institutions and universities to include online education as part of long-term strategy and goals has been almost a plateau. The continued success of online degree programs and gained support from industry partners and collaborations will also motivate organizational support.

All of the components described above supports the development of the Systems Engineering Framework (Exhibit 5). The systemic view establishes the definition and boundaries of the system, the subsystem, the components, and the constraints that are imposed upon the system; the life-cycle starts with the identification of a need, and is followed by the conceptual design, preliminary design, detailed design and development, production and/or construction, and operational use and support phases.

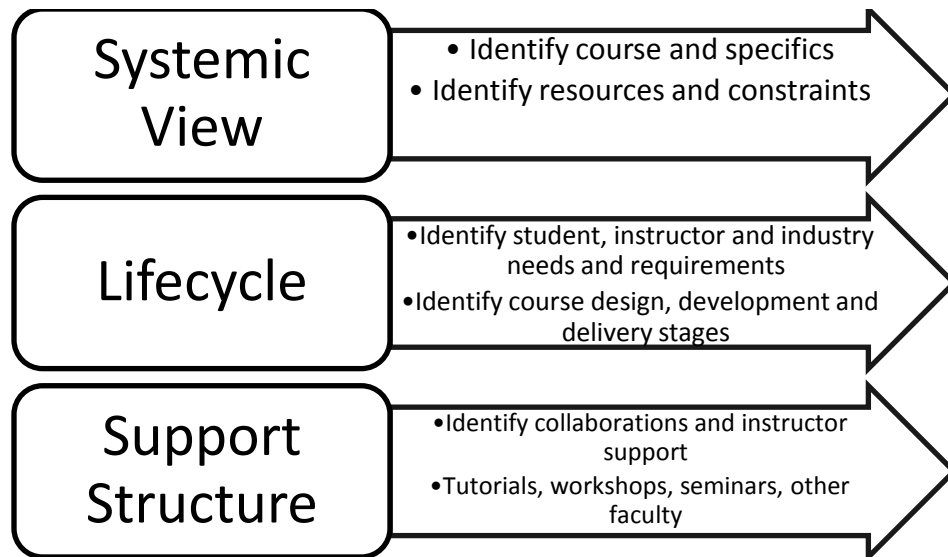


Exhibit 5. Systems Engineering Framework

#### 4 CONCLUSION

The systems engineering-based framework described in this paper is intended to provide academicians with an effective and rigorous approach to design and develop online courses. The significance and utility of the developed framework is twofold: Repeatability and transferability. Usually, faculty members are required to develop an online course every semester, as well as teaching face-to-face courses. Having a framework to assist them in each online course will not only be helpful, but also ensure consistency in the online course design and delivery. The generalizability of the framework makes it easier to transfer from one course to another or from one discipline to another. The SysEF framework can be used for a business course, just as it is used here for an engineering management course, since it is context-free. Issues such as user requirements identification and feasibility analysis, for instance, are valid for all disciplines. One of the main future research topics that stem out of this research is the application of the framework. Using the framework to guide the transition of a face-to-face class to an online class will support the utility and highlight the value of the framework.

#### REFERENCES

- ASEE (2010) Profiles of Engineering and Engineering Technology Colleges.
- Blanchard, B. S. (1998) System Engineering Management. Wiley-Interscience: 2nd Edition.
- Blanchard, B. S. (2008) System Engineering Management. Wiley-Interscience: 4th Edition.
- Change the Equation, Retrieved from <http://www.changetheequation.org/what/our-mission-and-goals/> on September 28, 2010
- Fabry, D. L. (2009). "Designing Online and On-Ground Courses to Ensure Comparability and Consistency in Meeting Learning Outcomes" *Quarterly Review of Distance Education*, Vol. 10, No. 3, pp. 253-261.
- Faulconbridge, R. I. and Ryan, M. J. (2003) Managing Complex Technical Projects: A Systems Engineering Approach. Artech House, Inc.

- Hirumi, A. (2005) "In Search of Quality: An Analysis of e-Learning Guidelines and Specifications" *Quarterly Review of Distance Education*, Vol. 6, No. 4, pp. 309-330.
- INCOSE (2010). *Systems Engineering Handbook v. 3.2: A Guide for System Life Cycle Processes and Activities*.
- Instructional Technology Council, "2008 Distance Education Survey Results: Tracking the Impact of eLearning at Community Colleges" 14 April 2010.  
<http://www.itcnetwork.org/mod/resource/view.php?inpopup=true&id=77>
- Mayadas, A. F., Bourne, J. and Bacsich, P. (2009) "Online Education Today" *Journal of Asynchronous Learning Networks*, Vol. 13, No. 2, pp. 49-56.
- Reuter, R. (2009). "Online Versus in the Classroom: Student Success in a Hands-On Lab Class" *The American Journal of Distance Education*, Vol. 23, pp. 151-162.
- Sloan Survey (2009). I. Elaine Allen and Jeff Seaman, "Learning on Demand: Online Education in the United States"
- Smith, D. E. and Mitry, D. J. (2008). "Investigation of Higher Education: The Real Costs and Quality of Online Programs" *Journal of Education for Business*, January/February, pp. 147-152.
- Wilkes, R. B., Simon, J. C. and Books, L. D. (2006). "A Comparison of Faculty and Undergraduate Students' Perceptions of Online Courses and Degree Programs" *Journal of Information Systems Education*, Vol. 17, No. 2, pp. 131-140.