Transforming Engineering Curricula through Web-based Interactive Visualization and Simulation Modules

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Abstract

This paper discusses pedagogical improvement in engineering education that can be made through integration of visualization and simulation modules in undergraduate curricula. The authors are leading a planning effort to transform the existing engineering curricula to visualization and simulation enhanced curricula. The emphasis is on providing interactive visualization and simulation modules that will transform classrooms from being vehicle of passive transfer of knowledge to an interactive learning environment. This will accelerate the pedagogical changes that would transform learning process from being teacher-centric to student-centric. The web-based modules also have potential of becoming the building blocks for web-based engineering programs. These web-based programs when created will become the agent for global cooperation among educational institutions in different countries. Various factors that currently favor engineering curricular transformation using visualization and simulation are also described. Two examples of web-based visualization and simulation modules are discussed. The first one, the web-based virtual supersonic module, is a comprehensive tool that provides students the engineering principles, governing equations, physical configurations and applications of high speed nozzles. It also has an interactivity feature that allows students to create and visualize various flow regimes in one-dimensional compressible flows. The second example pertains to a web-based virtual experiment that replicates many features of its physical analog. The virtual experiment titled “Virtual Venturimeter” is a part of development effort to map the Thermo/Fluids Lab into a web-based virtual lab.

Keywords: curricula transformation, visualization, simulation, engineering education, web-based engineering education

Engineering Education - Poised for a Change

Currently, many US companies work in a globally competitive environment and need engineers who can design and produce innovative products quickly and at competitive prices. Global cooperation often makes simulation the preferred design tool. A growing number of companies now require entry-level engineers to have skills and technical know-how to allow
them to become productive as soon as they enter the workforce. Academia is beginning to respond to these requirements by developing strategies to bring engineering educational programs into alignment with the current industrial environment [1-2]. The emphasis should not be on simply providing engineering science principles, but also on familiarizing students with the elements of engineering practice, or what Penfield and Larson [3] call “engineering know-how”.

The downward trend in recent years in the total number of credit hours required for undergraduate engineering degrees precludes increasing the number of laboratory hours in order to provide students the additional hands-on experience (engineering “know-how”) to meet the needs of industry. An alternative way, and perhaps even a better and more cost effective way, to provide enhanced hands-on experience to students is to make use of the virtual domain through interactive courses and learning modules that use visualization to recreate physical phenomena. Recent advances in computer hardware, software and visualization technology make this possible. Some industrial leaders, as well as educational leaders, have suggested that computer modeling and visualization be used in an interactive mode to provide students hands-on skills now being demanded by industry [1-3]. Visualization has always been a critical factor in a successful engineering program, largely through physical laboratory experiences. In fact, the ability to visualize a physical process is essential for engineers to work successfully in industry [4-6]. Rapid advances in computer and communication technologies in the past ten years have opened a new avenue for providing hands-on skills to students through visualization in the virtual domain. According to Kartemeyer and Bauer [7], “We are now on the threshold of the ability to use the emerging computing and communications technologies in education to mediate and augment interactions among teachers and learners.” In fact in recent years, several papers have been published that propose the integration of visualization in the virtual domain in a variety of undergraduate engineering courses [8-22]. This is done primarily through visualization modules for lecture or lab classes. Previous studies have demonstrated that computer simulations can substitute real-life, hands-on laboratory experience [23].

Reasons for Emphasizing Simulation and Visualization in Engineering Education

There are at least five primary factors that support the claim that visualization of physical phenomena in the virtual domain through computer simulation will become a powerful learning tool in the near future.

1. Industry Perspective

Increasingly, industry relies on computer simulation and visualization technologies to eliminate expensive mock-up experiments. For instance, the Boeing Aircraft Company, a pioneer in the use of computers in the design of aircraft, has used the “fly through” computer program to design the entire Boeing-777 aircraft in the virtual domain by making extensive use of the CAD program, CATIA [2]. Also, automobile, computer, and consumer goods manufacturers are already using computer software and visualization extensively for designing and manufacturing products. In fact, the definition of “hands-on experience” is also changing because industry is relying more and more on computer simulations and visualization, and as a result the term does not necessarily imply dealing with physical hardware only. It is imperative that engineering schools incorporate these tools across the curricula to reflect such a state of technological evolution. An academic leader quoted in Ref. 1 stated, “All of the [engineering] disciplines have
to have a good, strong understanding of the computer work world. And as a result, we find more
and more employers insisting that most of our graduates have a strong computer background.”

2. Student learning styles

The second factor relates to the changing background of incoming engineering students,
as compared to that of students of the pre-personal-computer era. Current students are more
familiar with computers, the Internet, and interactive video games; as a result, they are more
attuned to a learning style based on visualization. One academic leader aptly remarked [1], “I
think it’s the television and the computer, and video games - that they can play at home either on
their television set or on their personal computer - I think the interactive nature of these games -
the live action - I think, that’s what has changed the way students learn. They are not nearly as
passive as my peers were when I was a college student.” However, many engineering faculty
have not fully utilized opportunities for making innovative curricular changes using computers.
This is partly due to the dogma that hands-on experience in engineering curricula can be
obtained only through physical laboratories. In light of the previous discussion, it is evident that
this is not entirely true, and that a well-educated engineer must be exposed to hands-on
experience in both physical and virtual domains. The faculty’s thinking can largely be attributed
to the fact that many of today’s engineering professors were educated before the proliferation of
personal computers and the Internet and therefore are slow to adjust to these new educational
tools.

3. Advances in technology

The third reason for the proposers’ optimism for the success of the vision put forth in this
proposal is the standardization and proliferation of open architecture-based visualization
technologies such as Java, XML, CGI, etc. These technologies are a significant step forward in
the tools needed to create visualization modules compared to older approaches based on
proprietary and closed architecture methodology. Such recent paradigm shifts in visualization
technology, together with advances in the computer solution of physical phenomena and orders
of magnitude increases in computer power, make it possible to design truly interactive, realistic,
life-like virtual experiments, as well as engaging visualization modules. Considerable work has
been done in developing visualization modules and virtual experiments for integration in
courseware [8-22]. The maturation of visualization technology and the accumulation of
experience in incorporating visualization modules in courses make now the right time to
incorporate visualization, not in just one or two courses, but across the disciplines. Old
Dominion University has positioned itself to take advantage of this technology to advance
distance learning and has developed two research centers to further develop simulation and
visualization technology. Thus, the infrastructure for implementing the curricular transformation
is in place, and as a result it enhances the prospects for a successful transformation of present
engineering curricula to the visualization and computer software enhanced curricula.

4. Cost effectiveness

The fiscal realities of shrinking resources at state-supported institutions such as Old
Dominion University and the very high cost of replacing aging infrastructures, including
laboratories, has caused educators to look at other viable alternatives to provide students with
needed engineering know-how and skills. The information technology modified curricula,
utilizing visualization and computer software technologies, is a cost-competitive option for
providing hands-on experience in the virtual domain as an alternative to developing additional hardware-based laboratories for more hands-on, engineering practice-oriented education.

5. Changing demographics and globalization of education

In not so distant past, most engineering students pursued four-year engineering programs on a full-time basis. However, in recent years due to changing demographics an increased proportion of prospective engineering students are looking for opportunities to pursue engineering education on the web while working part-time or full-time in industry. This has increased pressure on engineering educators to offer undergraduate engineering programs in the anytime-anywhere mode. It is also interesting to note that global barriers have crumbled due to the Internet and prospects for web-based transnational engineering programs have brightened. Availability of engineering programs on the web in the future is also expected to cause mentor (a university in a developed nation) and protégé (a university in a developing nation) relationships to mushroom, thus benefiting a large number of aspiring students worldwide who may wish to pursue engineering education in the distance learning mode.

Curricular Transformation through Web-based Visualization and Simulation Modules Embedded in Courses

Ideas proposed here are very much inline with the NSF-sponsored workshop [25] titled “Information Technology and Undergraduate Science, Mathematics, Engineering, and Technology Education: Challenges and Opportunities.” The authors in Ref. 25 remarked, “First, these tools can enable students to simulate, visualize, and experiment with complex real-world scientific problems, thus promoting, exploratory and inquiry-based modes of learning. Second, information technology can enable collaboration, interactive learning, and vital changes in pedagogy, leading to a restructuring of traditional modes of student-faculty interaction.” In order to remain engaged fully in the ongoing educational technology revolution, the Batten College of Engineering and Technology at Old Dominion University has developed a vision to transform its undergraduate curricula to simulation- and visualization-enhanced curricula. The emphasis is on pedagogical improvement that can be made in engineering education as a result of thorough integration of interactive simulation and visualization throughout the curriculum. The desired goal of transformation is to allow students to achieve a deeper understanding of basic principles, especially for phenomena difficult or impractical to illustrate in physical laboratories. In addition to replicating predetermined learning objectives in physical laboratories, the modules will encourage students to explore a wider range of system responses and “what-if” parametric scenarios.

The modules discussed in this study are based on the pedagogy of “Learning by Doing in the Virtual Domain” [24]. This pedagogy postulates that integration of advanced education technology tools such as interactive visualization and simulation modules in curricula will enhance student learning, improve quality of education, and will prepare graduates who possess the know-how to practice in a world transformed by computer and Internet technologies. The authors have received a grant from the National Science Foundation titled “Planning Grant: Simulation and Visualization Enhanced Engineering Education.” Using grant funds, eight faculty from three engineering departments (Civil, Electrical and Mechanical) have developed strategies and a framework for transformation incorporating simulation and visualization in undergraduate
courses to enhance student learning. An important objective of the NSF grant is to develop, test and assess a pilot visualization module as a proof of concept. A web-based module involving operation of a virtual supersonic nozzle (http://www.mem.odu.edu/simulations) has been developed for integration into the Thermodynamics II Course, a course dedicated to practical applications of thermodynamic laws. The module has two distinctive features. First it promotes active learning through a user friendly and interactive modular design. This feature is expected to transform students from passive to active fully engaged learners. Secondly, the module has been designed to provide students the practical context by including a variety of practical applications and phenomenon involving supersonic nozzles.

The virtual supersonic nozzle module is quite comprehensive and provides information about governing equations, the physical principles, and practical applications. The schematic of the supersonic nozzle module is shown in Fig. 1. The virtual interactive part of the module permits students to operate the nozzle in the virtual domain by specifying the upstream and downstream (back) pressures to explore how the normal shock wave moves through the diverging section of the nozzle as the back pressure is changed. The virtual supersonic nozzle module after testing has been integrated in the ME 312 (Thermodynamics II) course. The module is so designed that students can use the clicking and dragging action of the mouse to visualize variation of flow properties for both isentropic (shock free) and non-isentropic (normal shock embedded) flows. The clicking action at any point opens a box window indicating flow property values at that point (Fig. 2).

Fig. 1 Supersonic Wind tunnel with a Converging-Diverging Nozzle
As stated earlier a variety of visualization and simulation tools are currently available, both in commercial as well as in public domain. They can be classified into following three categories.

1. **Visualization Modules**
   Visualization module can be of two types. In the first category visual images of an actual physical phenomenon can be used to make students aware of engineering context of governing equations and physical principles. For instance, in the case of the supersonic nozzle module discussed earlier, it is well known that the shock diamonds are formed in the exhaust plume of rocket and engine nozzles (Fig. 3). These visual images provide students the motivation to determine conditions under which shock diamonds occur in real life. The second category of visualization module involves computer simulation and visualization of a physical phenomenon through computer generated images. The interactive virtual supersonic module shown in Fig. 1 is one of the examples of this category.

2. **Simulation Modules**
   In many cases simulation of a physical process using software may be of primary interest and visualization of the phenomenon may be of secondary interest. In these cases, students using computer software may wish to explore a wider range of system responses and “what if” parametric scenarios that are the intrinsic nature of the engineering analysis

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**Fig. 2 A Snapshot of the Virtual Supersonic Converging-Diverging Nozzle with a Box Window for Flow Properties**

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and design processes. Many well known commercially available computer software for
design, analysis and optimization fall into this category.

Fig. 3 Diamond (oblique) shocks in space shuttle and rocket exhaust plumes (Courtesy NASA)
3. Web-based Virtual experiments

A web-based virtual experiment is a computer generated experiment that mimics many important aspects of a physical experiment such as virtual experimentation, data acquisition, hands-on experience and collaboration. Virtual experiments can be employed in a variety of ways in engineering education. For example, it can be used by students as a practice tool before performing the corresponding physical experiment. This will reinforce student learning and provide them with opportunity to gain hands-on experience in both physical and virtual domains. For instructors who teach in mediated (technology enhanced) classrooms, a web-based virtual experiment can be a valuable tool for demonstrating a phenomenon, clarifying concepts and enumerating “what if” scenarios to transform lecture classes to a setting for dynamic learning. Also, the web-based virtual experiments, if designed properly, can potentially become building blocks for virtual laboratories for undergraduate engineering programs on the web.

The authors have recently developed the virtual experimentation methodology that uses an animation program (Macromedia “Flash”) powered by computer simulation data to visualize a physical phenomenon in the virtual domain and to make virtual measurements [26]. This methodology has been used to map a physical experiment in the Thermo/Fluids Laboratory titled “Venturimeter as a flow measuring device” into a web-based virtual experiment, Fig.4 (www.mem.odu.edu/virtuallab). Students are able to conduct this experiment interactively on the web by manipulating a flow controlling valve to change the flow rate through venturimeter, and measure heights in piezometer tubes directly on the computer screen. For each selected flow rate, students measure the pressure change between sections with maximum (inlet) area and minimum (throat) area to determine the coefficient of venturimeter, a parameter that represents frictional losses. Once the venturimeter is calibrated by determining its coefficient, it can be used to determine unknown flow rates by measuring pressure changes between the inlet and throat sections.

![Fig. 4 Venturimeter as a flow measuring device](image-url)
Conclusion

Web-based visualization and simulation modules offer significant potential for modernization of engineering education. They enable students to learn more in depth about physical phenomenon through both physical and computer generated images. The authors strongly believe that these emerging technology tools must be coupled with basic math, science, engineering and physical laboratories. In other words, visualization and simulation should not replace engineering analysis and problem solving but reinforce it. Visual images projected on computer screen without making connection to analysis and underlying governing equations may not give students the depth in understanding of a phenomenon. Consequently, it is important that visualization and simulation modules be designed and embedded in courses in a manner so as to enhance students problem solving skills by making connections between visual images of the phenomenon projected on the computer screen and the underlying principles and governing equations. Universities still are lagging behind state-of-art industries and advance video gaming in the area of simulation and visualization. Spectacular recreation of physical phenomena in movies by special effect artists indicates that a lot more needs to be accomplished to make engineering education more dynamic and interesting. Our own limited experience shows that visualization and simulation modules have significant potential to transform learning process from traditional teacher-centric mode to a more student-centric mode. This transformation we believe will produce more knowledgeable, mature and better trained students capable of meeting challenges posed by globalization.

Bibliography


Bibliographical Information

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