Simulation and Visualization Enhanced Engineering Education

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Abstract

The present work describes an ongoing project, supported by National Science Foundation, whose goal is to enrich student learning by implementing an undergraduate engineering curricula transformation that will incorporate simulation and visualization modules in 14 engineering science and engineering core courses in three disciplines namely Civil and Environmental Engineering (CEE), Electrical and Computer Engineering (ECE) and Mechanical Engineering (ME). Twelve faculty members from these three departments are participating in the transformation. This paper describes the framework for the curricular transformation, and identifies five modular characteristics that are expected to play important role in the development and implementation of simulation and visualization modules. These characteristics namely interactivity, practicality, interconnectivity and hierarchy are described in some details with examples. The project is expected to have long term educational and career benefits to a large number of students and faculty who will be affected by the curricular transformation. Integration of advanced education technology tools such as interactive visualization and simulation in engineering curricula is expected to enhance student learning and improve quality of engineering education.

Introduction

Paradigm changes in recent years in computer, communication and internet technologies, what many have termed as the digital revolution, has bought down transnational barriers, and has changed radically the way in which industrial organizations do business. Many facets of engineering profession such as research, design, development and manufacturing, once localized within national boundaries, have become truly globalized. Frontiers of computational techniques such as Computational Fluid Dynamics (CFD), Computer-Aided Design (CAD) and Finite Element Analysis (FEA) have advanced so much that they have transitioned from being scientific tools for simulating complex physical phenomena based on conservation principles, to engineering tools for analysis and design. Maturation of computer software technologies such as simulation and visualization has made it possible for engineering designers to analyze and evaluate in the virtual domain "what if parametric scenarios" that are the intrinsic nature of engineering analysis and design processes in engineering practice. These new developments have become catalysts for creation of a new field, Virtual Engineering, which uses computer and internet-based design, analysis and decision making tools for developing and evaluating different design options in the virtual domain, without engaging in costly mock-up experiments [1].

This rapid transformation of industry into a globally interconnected enterprise has not gone unnoticed in academia, especially in engineering education. A study commissioned by the National Academy of Sciences in 2005 titled "Educating The Engineer of 2020: Adapting Engineering Education to The New Century", describes the use of information technology-enabled learning as being in its infancy and recommends further research on web-mediated learning [2]. The study also recognizes that new information technology tools will change the learning environment in engineering education from primarily teacher-centric to student-centric. Unfettered access to web-based educational materials will be useful to all students but more so to part-time students who will be able to interact with materials at their own convenience. An important aspect of student-centricity is that students will be able to set their own pace of learning, with teachers playing the role of guides in the learning process. The publication "How People Learn", by the National Research Council [3] also emphasizes the importance of research on learning, especially the ways information technology can enrich the student learning process.

In order to meet the growing demand for engineers who are well-versed with computer and Internet-based tools for problem solving, engineering educators are increasingly incorporating in curricula information technology-based learning tools such as web-based multimedia modules, virtual collaborative environments, virtual laboratories, software for simulation and visualization of physical phenomena etc.[4-10]. The two-fold objective of this ongoing transformation is: (i) to improve the quality of instruction with innovative course materials that cater to the learning styles of present generation students, and (ii) to provide students exposure to computer and Internet-based problem solving tools so as to facilitate their transition from academia to industry. It is noteworthy that present day engineering students have an early exposure to computers, Internet and video-gaming as compared to their counterparts a generation ago. As a result, current students are more comfortable in using web-based instruction tools for learning. It has also been recognized by many engineering educators that 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 [11]. It is imperative that engineering schools incorporate these tools across the curricula to reflect such a state of technological evolution.

Objectives of Present Study

The present work, supported by an ongoing National Science Foundation grant, is investigating ways in which engineering curricula at Old Dominion University can be transformed into simulation and visualization enhanced engineering curricula. Twelve faculty members from three engineering departments, Civil and Environmental Engineering, Electrical and Computer Engineering and Mechanical Engineering, are participating in the transformation. The emphasis is on incorporating interactive modules that use simulation and visualization to enhance student learning. In development of modules, the pedagogy of “learning-by-doing in virtual environments” is being employed. One of the important ways engineers learn is through hands-on activities in physical laboratories. The web-based modules are expected to complement student learning achieved through physical laboratories and conventional classroom instruction. Dede has explored this pedagogy of “Learning by doing” for distance education [12]. However our emphasis is not as much on distance learning but on enhancing quality of student learning by embedding web-based interactive modules in conventional on-campus classes.

The primary goal of the ongoing project is to demonstrate that pedagogical improvements can be made in engineering education as a result of thorough integration of interactive simulation and visualization throughout the curriculum. The focus is on interactivity both inside and outside of classes so that students can obtain hands-on experience in local and distributed virtual domains in addition to what they generally learn in laboratory courses. In addition to replicating predetermined learning objectives in physical labs, these modules will encourage students to explore a wider range system responses and “what if” parametric scenarios. The desired objective is to allow students to achieve a deeper understanding of basic principles, especially for phenomena difficult or impractical to illustrate in physical laboratories. Initially the transformation is being applied to selected engineering science and core engineering courses in the three disciplines and will be followed by transformation of specialized senior level courses in a subsequent phase.

Framework for Transformation

In a faculty survey conducted recently in the College of Engineering and Technology at Old Dominion University, 70% of the ME faculty, 60% of CEE faculty and 60% of ECE faculty expressed interest in using visualization and simulation as educational tools for enhancing instructional quality of their courses. The survey also indicated that most engineering disciplines in the college currently do not employ interactive visualization and simulation modules for learning enhancements. This is particularly true for most engineering science and engineering core courses in which traditional learning style without visualization and simulation is still practiced. Since courses in different discipline may use different methodologies, it may not be desirable to prescribe a one-size fits all approach. A consensus has developed among participating faculty that each faculty should be provided flexibility and latitude in module development and implementation with the caveat that certain common elements and characteristics that are considered as critical for a successful transformation be preserved.

The common elements are: (a) visualization of a physical phenomenon, (b) simulation of a physical process, (c) integration of virtual experiments. In order to meet the criterion for a successful transformation at least two of three elements must be present in a transformed course.

Modular Characteristics

In order to maximize the impact of simulation and visualization, a module should include an optimal mix of following five characteristics that have been identified for the curricular transformation. These modular characteristics are: (i) interactivity; (ii) practicality; (iii) interconnectivity; (iv) hierarchy and (v) Viscompana (Visualize, compute and analyze). Only first four characteristics are described in this paper. It is noted that these modular characteristics are intimately related to knowledge, comprehension and exploration as per the Bloom's Taxonomy of Educational Objectives [13]. Figure 1 illustrates in a pyramidical structure of learning showing the connection between the five modular characteristics and the learning objectives identified in Bloom's taxonomy.

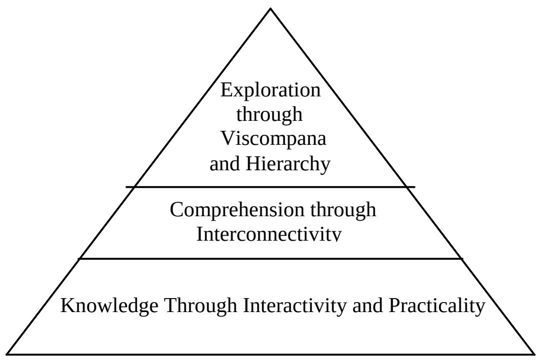

Figure 1: The Learning Pyramid

Interactivity

It refers to students' ability to interact with a module. This characteristic helps transform classrooms from a vehicle of passive transfer of knowledge to an active student-centered learning environment. For example, Fig. 2 shows a web-based supersonic nozzle visualization module (http://www.mem.odu.edu/schockwave) designed to teach students about one-dimensional compressible flows, students can interact by accessing the virtual interactive sub-module to simulate isentropic (shock-free) and non-isentropic (normal shock embedded) flows by adjusting upstream and downstream pressures. They can also visualize flow property variations by the clicking action of the mouse that acts like a measuring probe. The clicking action of the mouse at any point in the flow field creates a window containing all the flow properties, generated by solution of conservation equations for mass, momentum and energy (Fig. 3). This module was implemented in the undergraduate applied thermodynamics course.

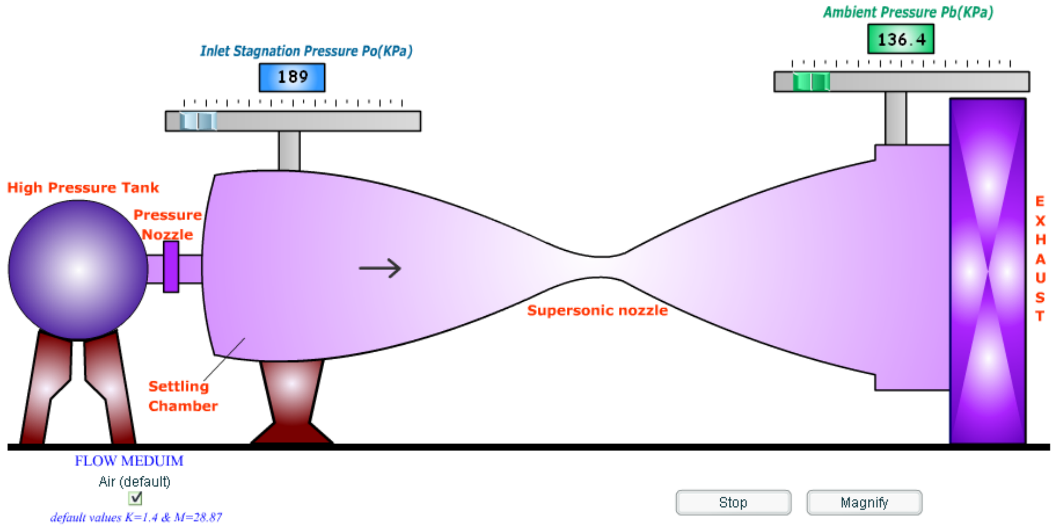

Figure 2: Supersonic Wind tunnel with a Converging-Diverging Nozzle

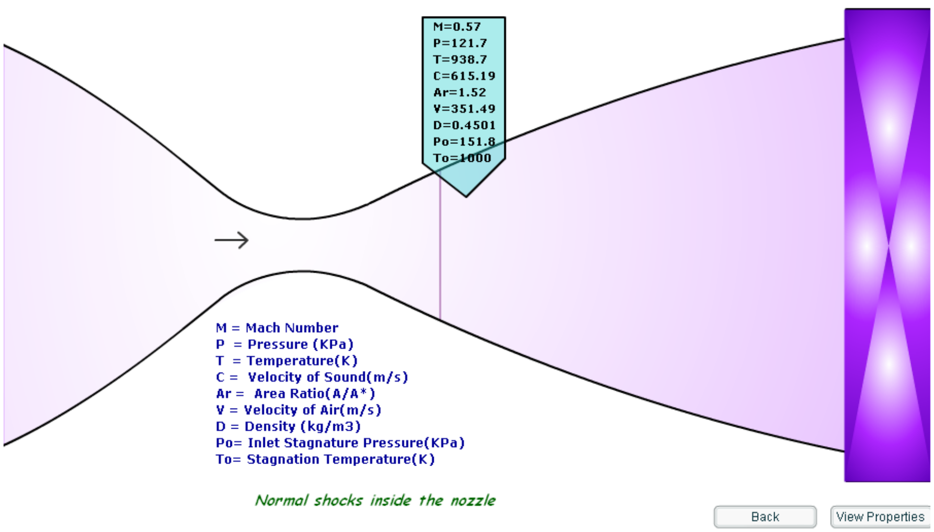

Figure 3: Visualization of flow properties by clicking action of mouse

Practicality

This characteristic relates to a module's emphasis on engineering context (real world aspects) of engineering principles and governing equations underlying the module. For example, the physical sub-module of the supersonic nozzle visualization module discussed earlier, provides students with examples and visual images of rocket and jet engine nozzles. Students are also able to see many still video images of non-isentropic phenomenon outside the nozzle, manifested as oblique shocks and expansion waves resulting in shock diamonds for both rocket nozzles and jet-engine nozzles (Fig. 4). Using the module, students are able to determine the range of ambient to stagnation pressure ratio parameter for which shock diamonds will occur outside the nozzle. These virtual interactive exercises help students relate an observed phenomenon to operating parameters that govern it.

Figure 4: Shock Diamonds in Jet engine nozzle exhaust (courtesy: NASA Photo Gallery)

Interconnectivity

It describes a module's capability of building on students' knowledge and experience in preceding courses or subject materials and projecting that to future learning. For instance, in the supersonic visualization module, instead of using air as a medium, students are required to use combustion products as the flow medium. Students use thermodynamics laws to analyze and compute properties of combustion products such as mixture molecular mass, specific heat ratio and combustion products temperature as a function of air-fuel ratio. These student-generated properties are input in the supersonic visualization module (Fig. 2) to examine effects of changing flow medium properties on nozzle characteristics such as thrust. The supersonic visualization module has been developed to instill in students a sense that various topical areas of thermodynamics such as gas mixtures, combustion and one-dimensional compressible (nozzle) flows are interconnected. Fig. 5 illustrates interconnectivity between the topical areas of mixtures, combustion and one-dimensional gas dynamics.

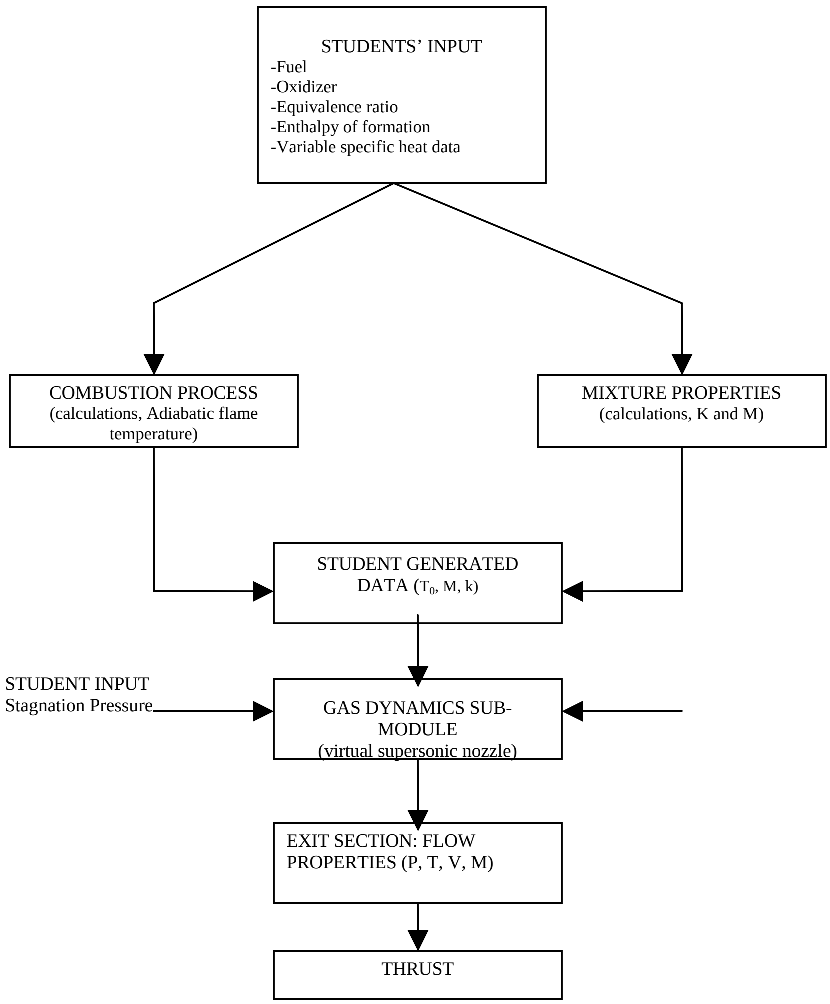

Figure 5: Example of Interconnectivity

Hierarchy

This refers to a module's capability of guiding students from elementary considerations to more advanced learning through sub-modules that are embedded into one-another, with succeeding sub-modules providing a higher level of learning compared to the preceding one. For example in the thermodynamic gas power (Brayton) cycle module being developed for the introductory thermodynamics course in the mechanical engineering curriculum, the first level of hierarchy deals primarily with conventional topics such as energy balances and parametric variations of cycle efficiency (for power generation) or thrust (for propulsion). The second level provides students visual images and physical configurations of various types of compressors and turbines to illustrate concepts related to multi-staging (Fig.6). The third and yet advanced level provides opportunity to students to become familiar with velocity diagrams and stage efficiency, and allows them to integrate performance of individual compressor and turbine stages into overall performance. The hierarchical arrangement of subject matter permits students to set their own level of learning goals and set their own pace to achieve them. The hierarchy characteristics of the web-based module will facilitate exploration by students to learn about topics and aspects that would normally will not be covered in conventional classroom setting.

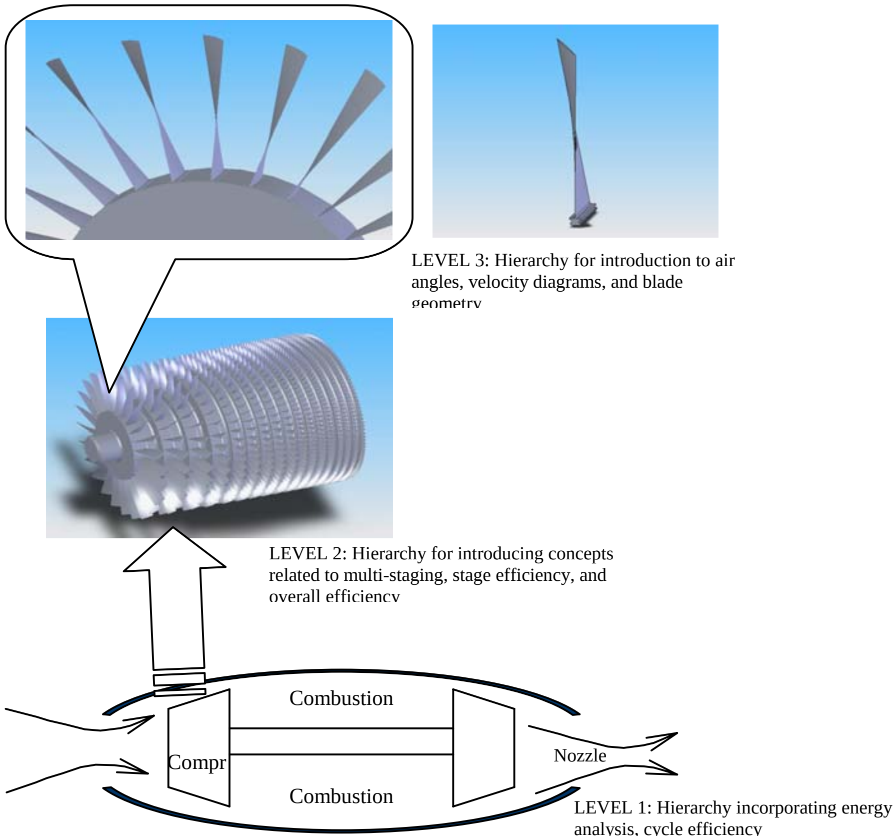

Figure 6: Gas Turbine (Jet Engine) Cycle

Conclusion

The College of Engineering and Technology at Old Dominion University has made a long term commitment to fully integrate visualization and simulation in all engineering disciplines to enhance the quality of education and to graduate engineers who have the engineering know-how to practice successfully in industries that are relying more and more on information technology to achieve productivity gains. Simulation and visualization have proven to be great tools for movie and video-gaming industries. They have enabled graphic artists and designers to create movie scenes that would otherwise be hard or impossible to create in the physical realm. Our experience and that of others in the field of engineering education indicate that simulation and visualization have great potential to enhance student learning and the quality of engineering education, by affording students opportunities to learn in the anytime-anywhere mode. Modularization of course contents into web-based interactive knowledge resource will also facilitate development of future web-based engineering programs that can use web-based modules as building blocks for web-based courses and laboratories. The web-based modules will also become vehicle for cooperation among participating international institutions as well as tools for training and professional development.

Acknowledgement

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