

A WEB-BASED SIMULATION AND VISUALIZATION MODULE FOR AN UNDERGRADUATE THERMODYNAMICS COURSE

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Abstract

A web-based module titled “Thermostates” was developed using simulation and visualization and was implemented in the junior level thermodynamics course in the mechanical engineering curriculum. It has been designed to provide an active learning platform to students for reinforcement of concepts and tools such as thermodynamic properties, tables, diagrams and ideal and non ideal gas behavior that are critical for problem solving. This module has been used for enhancing students’ learning gained through conventional classroom lectures. Students can access the module in the anytime/anywhere mode and can set the pace of learning in accordance with their academic capabilities. The module was implemented and assessed at two institutions, namely Old Dominion University (ODU) and East Carolina University (ECU). The effectiveness of the module was assessed on the Likert scale using students’ responses to a survey form that included questions pertaining to the subject matter in the module. Results indicate that students find the module an effective tool for enriching their learning experience in the course.

Introduction

A number of recent trends, namely advances in technology, changing student learning style and demographics and globalization of the engineering profession have set the stage for major changes in ways engineering students are educated. Advances in computer and web

technologies is creating new learning pathways that include video-streaming of web-based courses, virtual labs, multimedia courseware, web-based collaborative learning, simulators, visualization modules, etc.[1-20]. Students’ learning style is also becoming more visualization-based due to wide-spread exposure to computers, Internet and video games [21]. This has motivated engineering professors to recalibrate their teaching methods by developing educational resources that are geared towards technology-savvy visual learners. Engineering enrollment of geographically distributed part-time students, as well as adult learners, has steadily increased in recent years and has provided added incentive to offer web-based courses and programs. It is evident from these developments that web-based learning (WBL) will continue to play an important role in educating engineers of the next generation. The 2005 National Academy of Sciences report titled “Educating the Engineer of 2020: Adapting Engineering Education to the New Century”, recommended that more research be done on web-mediated learning [22]. Another publication “How People Learn” by the National Research Council also discussed the importance of technology-based tools for engineering student learning [23].

The time-tested conventional teacher-centric learning (TCL) model for educating engineering students is undergoing transformative changes due to factors mentioned earlier. Although live classroom instruction will remain an integral part of engineering education in the foreseeable

future, the teacher-centric education model will continue to evolve due to the embedding of education technology tools to enhance student learning effectiveness. Referred to as the technology enhanced learning (TEL) model, the student learning achieved through TCL is supplemented with technology-based tools that are often developed using interactive simulation and visualization. The traditional role of teachers as the sole agents for transferring engineering knowledge and skills to students through live classroom lectures is also poised for a change. As students avail alternative pathways for accessing engineering education, they are also being called upon to take more responsibility for their own learning. This has been referred to as student-centric learning (SCL) in the literature. In this modality students are no longer passive recipients of knowledge as is generally the case in a conventional classroom setting. Instead, students use active learning tools on the web, with round the clock access. An important feature of SCL, as mentioned by its proponents, is that students are able to set their own pace of learning, thus allowing web-based resources to cater to students with a wide-spectrum of learning capabilities. Since SCL is generally suited for very motivated students who tend to be self learners, it is expected that a majority of engineering students in the foreseeable future will continue to be educated through TEL in which TCL is richly supplemented through incorporation of active learning technology tools. This study presents results from a case study of a web-based technology tool that has been embedded in an undergraduate thermodynamics course to encourage students to become active learners.

Objectives of Present Study

The present work is an off-shoot of an NSF engineering education grant that investigated ways in which engineering curricula at Old Dominion University could be transformed into simulation and visualization enhanced engineering curricula. The grant involved embedding web-based simulation and

visualization modules in 12 courses in three disciplines namely, civil, electrical, and mechanical engineering. The primary objective was to develop, implement and assess these modules for supplementation of student learning achieved through conventional in-class learning. In the present work, a web-based simulation and visualization module, developed for the junior level introductory thermodynamics course in the mechanical engineering curriculum, is discussed. The web-based module titled "Thermostates" (<http://www.mem.odu.edu/thermostates>) serves as an active learning platform for students to learn about thermodynamic states of pure substances, thermodynamic diagrams and tables, and the ideal and non-ideal gas behavior. The latter is illustrated through the generalized compressibility chart. These are fundamental concepts and tools that are essential to development of student problem solving skills in the course. The past experience of authors has been that many students in their classes are unable to perform well in the problem solving phase of the course because of their poor understanding of basic concepts. This web-based simulation and visualization module has been designed to specifically remedy this problem by giving students unfettered access to learning material in the interactive learning mode.

The outcomes of the module are:

1. Students will have the ability to describe different states of a pure substance on T-v and P-v thermodynamic diagrams.
2. Students will be able to use saturated, superheated and compressed liquids tables to determine desired thermodynamic properties.
3. Students will be able to use generalized compressibility charts to determine compressibility factors for saturated or superheated or compressed liquid states.

The principal feature of the module is the interactivity achieved through simulation and visualization. Macromedia "FLASH" has been used as the software for achieving visualization

for a number of “what-if” scenarios demonstrated in the module. This software has good capabilities for creating two-dimensional interactive interfaces through animations. It is highly suitable for creating applications that can be uploaded on the web. In addition, one can code instructions in the “FLASH” scripting language to provide interactivity to users of the application. Also, “FLASH” has an extensive library from which one can adopt different interactive buttons displays and templates. Because of its’ compatibility with different operating systems and web-browsers, “FLASH” is the ideal choice for creation of web-based visualization modules, and it was used to create the web-based module discussed in this study. The module is designed to be user friendly, and one can navigate through it using the back button and/or home button on every web page.

Motivation for Developing the Module

Years of experience in teaching the first course of thermodynamics have shown that students traditionally have difficulty in comprehending concepts related to thermodynamic states and processes. They have also exhibited difficulty in using thermodynamic tables. Since thermodynamics is a problem-solving discipline, and thermodynamic tables are an important resource for determining thermodynamic properties, it is important that this issue be dealt with in a manner that is user friendly and compatible with current students’ visual learning style. Furthermore, the module should be available on the internet so that students can have unfettered access to the module for supplementation of learning. Consequently, the “thermostates” module was designed with these factors in mind. Students are taken through the module in a step-by-step manner to learn about thermodynamic states, properties and tables. The module also provides students the flexibility of learning at their own pace. Since these topics are covered quite quickly in lecture classes, this sometimes leaves a hole in students’ understanding of these concepts, and supplementation with the module is expected to fill this void in students’ learning.

Structure of the Module

There are four sub-modules dealing with four areas that are considered important for enhancing students’ understanding of thermodynamic states and tables. These areas are: (1) visualization of thermodynamics states of a pure substance; (2) thermodynamic tables; (3) ideal gas behavior; (4) non-ideal gas behavior and generalized compressibility chart. Identifying thermodynamic states of a pure substance (sub-module 1) and subsequently finding properties from thermodynamic tables (sub-module 2) are two interconnected areas that are important in most problems involving conversion of energy from one form to another. It has been the experience of the authors and, hence the motivation to develop this module, that a significant percentage of students in their classes have difficulty in visualizing and differentiating states such as compressed liquid, saturated liquid, saturated vapor and superheated vapor. In this module, these aspects are addressed through the visualization software. For instance, changes in thermodynamic states from compressed to superheated are illustrated through an animation that allows students to observe these changes in slow motion as the substance is heated at constant pressure (Figure 1). By rolling the mouse over points a to 1, one can observe different states visually. Thermodynamic tables, namely compressed, saturated and superheated, are introduced through an interactive table (Figure 2) listing seven cases involving properties, pressure (P), temperature (T), specific volume (v) and quality (x). Clicking on the link next to the case shown in the table produces a four-step procedure for first identifying the state as compressed or saturated or superheated through steps 1 to 3 (Figure 3), and then finding the properties from appropriate tables through step 4. Every case listed in the table in Figure 3 is illustrated through example problems that are solved visually. The example for the superheated steam table is shown in Figure 4.

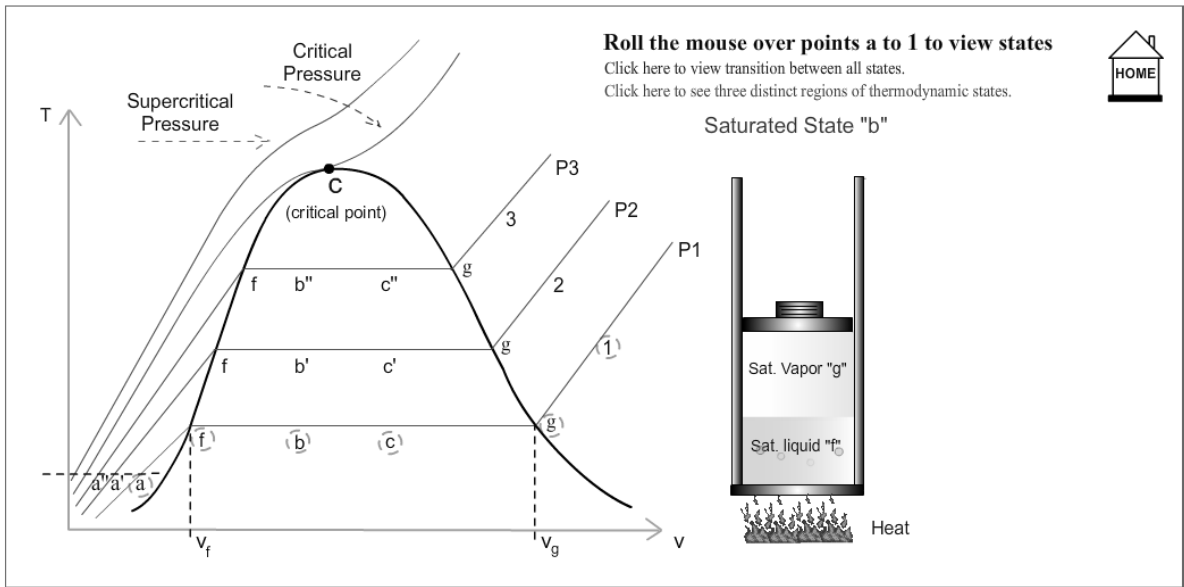


Figure 1: Screenshot of the changes in thermodynamics states.

Learning to use thermodynamic tables

HOME

It is recommended that a two-part procedure be used when using tables.

Part I: Fix the state (determine if the state is saturated, superheated, etc.)

Part II: Determine the required property value in the designated state.


Part I: The state is fixed by always accessing the saturation table.
 This is explained for a number of situations indicated in Cases 1 to 5, in the table shown below.

Case	Given	To find	Links
1	P, T	v	Next
2	P, v	T and/or x	Next
3	T, v	P and/or x	Next
4	P, x	T and v	Next
5	T, x	P and v	Next
Approximation of properties in compressed liquid states			Next
Definition of Quality (x)			Next

'v' represents specific volume (m^3 / kg)


'x' represents quality, a thermodynamic property. It is defined as the ratio of vapor mass (m_v) and the total mass (m) of the system.

Figure 2: Screenshot of the first step in fixing the thermodynamics state.



Case 1

Given P, T --- Find v


 BACK

Step 1: Choose P and go to the saturation table.

Step 2: For given P, find the saturation temperature (T_{sat})

Step 3: Compare T with T_{sat} .
 If $T > T_{sat}$ --- superheated state.
 If $T < T_{sat}$ --- subcooled liquid state.
 If $T = T_{sat}$ --- saturated state.

Step 4: Once the state is fixed (superheated, subcooled, etc.), you can use the corresponding table and find the v value.

[Click here to see visualization](#)

You can also use T as a starting point

Step 1: Choose T and go to the saturation table.

Step 2: For chosen T, find the saturation pressure value P_{sat} .

Step 3: Compare P with P_{sat} .
 If $P > P_{sat}$ --- compressed liquid state (same as sub-cooled liquid state)
 If $P < P_{sat}$ --- superheated state.
 If $P = P_{sat}$ --- saturated state.

[Click here to see visualization](#)

Figure 3: Screenshot of the four-step procedure for finding the thermodynamic properties.

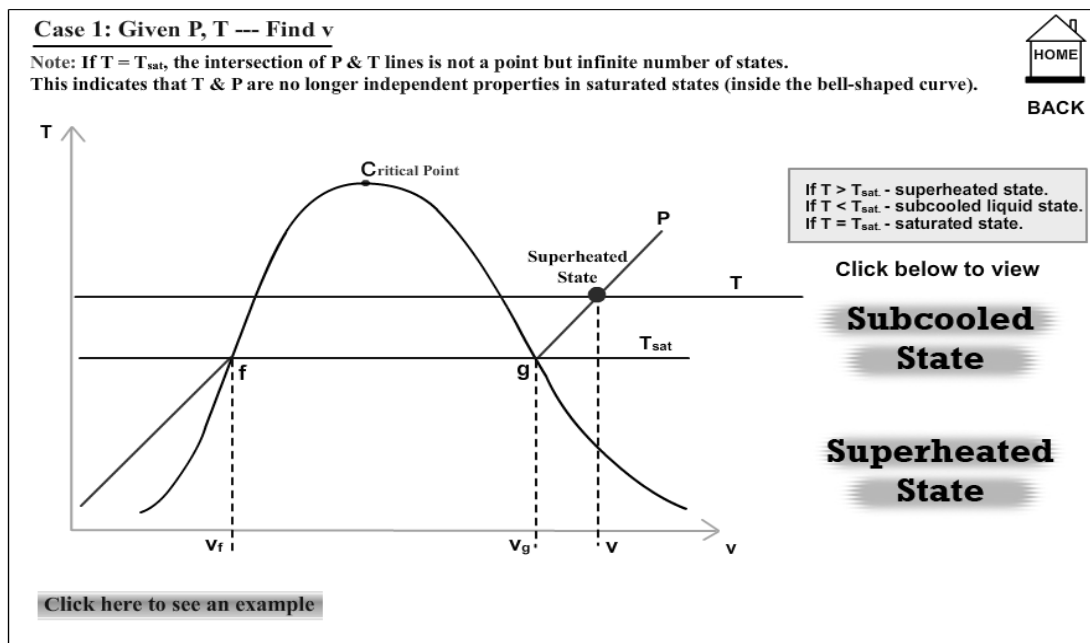


Figure 4: Screenshot of the superheated steam example.

The topic of non-ideal gas states is introduced through a generalized compressibility chart. The compressed liquid and superheated states are shown in an interactive table (Figure 5) in the module. For instance the superheated state visualized through this sub-module is shown in Figure 6.

Assessment of Student Learning

The module was implemented and assessed at two universities, namely Old Dominion University and East Carolina University. Students were given a survey form containing a

series of eight questions framed to capture qualitative feedback from students concerning various aspects of the four sub-modules. The survey form used the Likert scale of 1 to 5, with number one and five signifying students' strong disagreement and strong agreement, respectively with a posed question. The purpose of this qualitative assessment was two-fold: (a) to gauge students' perception (positive or negative) concerning the four sub-modules, (b) students' comments and suggestions for further improvement of the virtual experiment module. The questions of the survey are given below.

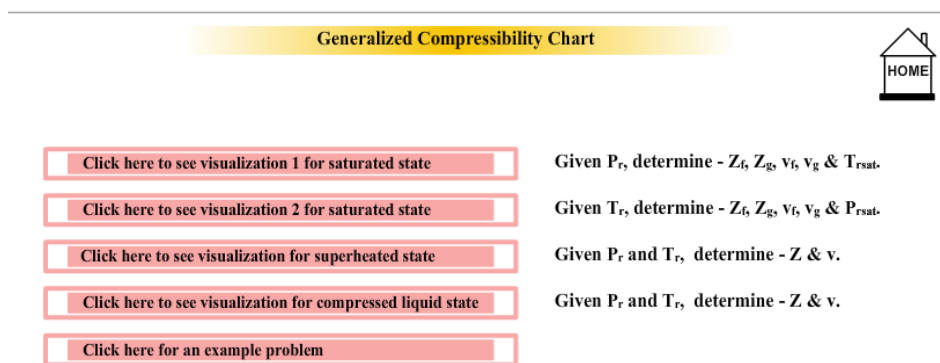


Figure 5: Screenshot of the generalized compressibility chart sub-module

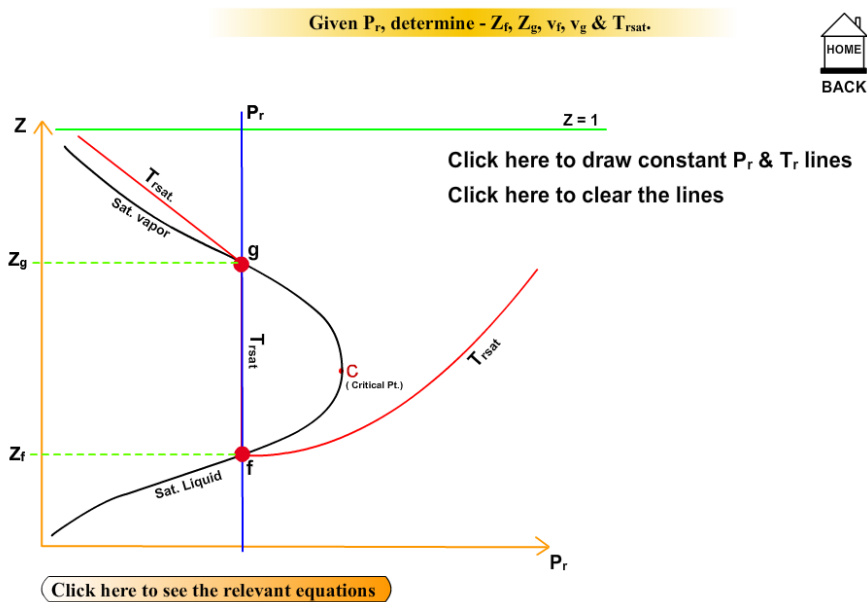


Figure 6: Screenshot of the superheated state visualization of the generalized compressibility chart sub-module.

1. The visualization module was helpful in understanding thermodynamic states of a pure substance.
2. The visualization module was helpful in understanding thermodynamic tables of pure substances.
3. The visual image in the module helped me understand interrelationships between various thermodynamic properties.
4. The visual images in the module will help me retain concept and other related information for a longer period of time.
5. The examples presented visually, were very helpful in understanding how to use thermodynamics tables.
6. The visualization module was user friendly.
7. It is recommended to use this visualization module in future classes.
8. More visualization modules of the type presented here should be developed for other topical areas.

The use of the module was voluntary and participation in the student survey process was also voluntary. As a result, eight out of about 40 enrolled students at ODU and about 21 out of 32 enrolled at ECU participated. The averages for the eight questions in the student surveys are shown in Figure 7. In general, the average rating of all question of the survey by ODU students and ECU students are 3.6 and 4.1, respectively on a scale of 1-5. Question 5 received the lowest average rating (3.3) suggesting that more examples are needed.

Figure 8 shows the percent of the students who rated 4 and 5 for all questions of the survey. The figure reveals that 100% of students are interested in seeing more modules in other thermodynamic topics and 80% of students are supportive of development of similar virtual modules in other courses as well.

The survey results pointed to two important factors that need to be addressed. First, students' use of the website did not reach the target level of 50 percent on a voluntary basis. To promote greater participation in the use of this website, in future offerings of the class, the introduction of a mini-project, involving the use of the module, would certainly be increased

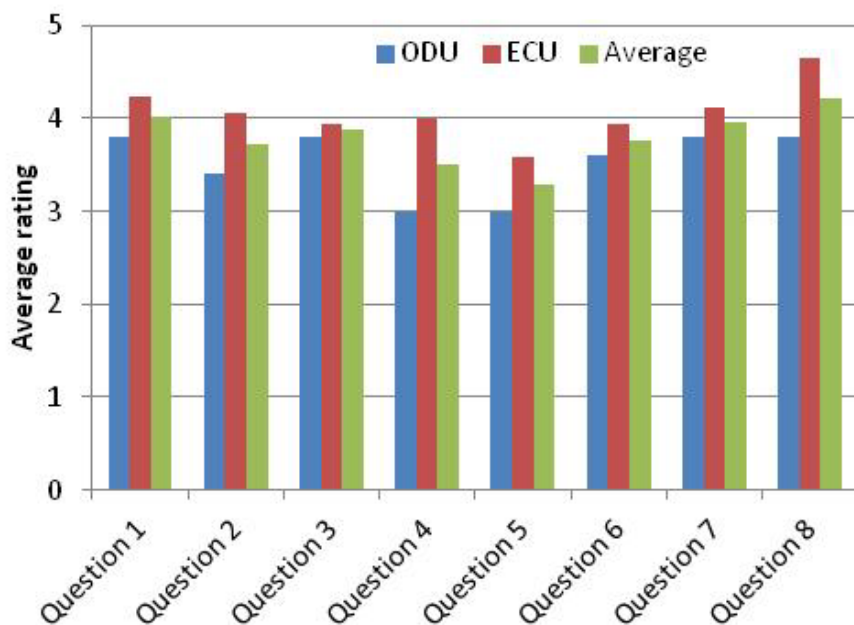


Figure 7: Results of the student feedback survey.

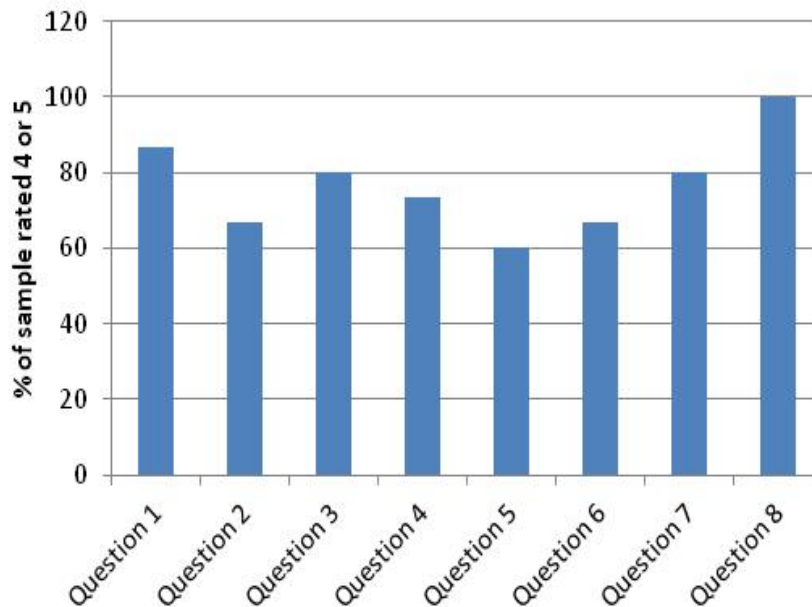


Figure 8: Percentage of sample rated 4 or 5 in the eight survey questions.

substantially due to graded nature of this assignment. The module, for results presented in this paper, was used primarily posterior. Students were asked to use it after presentation of the topic in the lecture classes. However, the module can also be used aprior, before the lecture classes, to prepare students for the upcoming classes. This again can be done through assignment of problems (to be graded) that require use of the module. These changes will also permit direct measure of student learning since assigned problems and projects will be graded.

Conclusions

A web-based module for teaching students about thermodynamic properties, tables, diagrams and ideal and non ideal gas behavior that are critical for problem solving is developed, implemented and assessed. The web-based module was developed using Macromedia "FLASH". The module was assessed using a student feedback survey form and given to students at two universities, Old Dominion University and East Carolina University. Students' feedback indicates that students find

the module useful and indicates their support for development of more modules in other topical areas in other courses.

Acknowledgement

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References

1. Bjorklund SA, Colbeck CIL. The View from the Top: Leaders' Perspectives on a Decade of Change in Engineering Education. *Journal of Engineering Education*. 2001;90(1):13-9.
2. Gorman ME. Transforming the engineering curriculum: lessons learned from a summer at boeing. *Engineering Education*. 2001;90(1):143-9.
3. Pennfield P, Larson RC. Education via advanced technologies. *IEEE TRANSACTIONS ON EDUCATION*. 1996;39(3):436-43.

4. Yang J, Anderson MD. Teaching tool shows results through visualization. *IEEE Computer Applications in Power*. 1998;37-42.
5. Overbye TJ, G. Gross, Laufenberg MJ, Sauer PW. Visualizing power system operations in the restructured environment. *IEEE Computer Applications in Power*. 1997;12(1):120-30.
6. Regan M, Sheppard S. Interactive multimedia courseware and the hands-on learning experience: an assessment study. *Engineering Education*. 1996; 85(2):120-30.
7. Huston JC, Barrance PJ, Heimcke C. Multimedia courseware in the instruction of undergraduate dynamics. *Conference Multimedia courseware in the instruction of undergraduate dynamics*. p. 162-7.
8. Oloufa AA. *ASEE Annual Conference Proceedings*. Conference ASEE Annual Conference Proceedings, Edmonton, Canada. p. 2742-5.
9. Campbell J, Bourne JR, Mosterman P, J. BA. The effectiveness of learning simulations for electronics lab. *Engineering Education*. 2002;91(1):81-7.
10. Rojas EM. Use of web-based tools to enhance collaborative learning. *Engineering Education*. 2002;91(1):89-95.
11. Burleson W, Grant A, Harris I. Educational innovations in multimedia systems. *Engineering Education*. 2001;90(1):21-31.
12. Wankat PC. Integrating the use of commercial simulators into lecture courses. *Journal of Engineering Education*. 2002;91(1):12-23.
13. Baker J. Articulate virtual labs in thermodynamics education: A multiple case study *Journal of Engineering Education*. 1999;88(4):429-34.
14. NSF workshop on information technology and undergraduate science, mathematics, engineering and technology education: Challenges and opportunities. *IEEE Transactions on Education*. 1996;3(3):452-4.
15. Chaturvedi S, Abdel-Salam TA, Muthoju P, Shrinivas S, Gagrani V. Mapping of a Thermo-fluids Laboratory Experiment into a Web-based Virtual Experiment for Application as a Prelab Practice Tool. *INNOVATIONS 2007: World Innovations in Engineering Education and Research 2007*.
16. Chaturvedi S, Abdel-Salam T. A web-based module for teaching engineering students about environmental effects of fossil fuel combustion. *Computers & Education Journal*. 2007;17(4).
17. Chaturvedi SK, Dharwadker K. Simulation and visualization enhanced engineering education development and implementation of virtual experiment in a laboratory course. *ASEE annual conference 2011*.
18. Bhargava, al e. Wb-based virtual torsion laboratory 2006.
19. Hashemi J. Web-based delivery of laboratory experiments and its effectiveness based on student learning style. *Conference Web-based delivery of laboratory experiments and its effectiveness based on student learning style*.
20. Jia R, al. e. A virtual laboratory on fluids mechanics. *Conference A virtual laboratory on fluids mechanics*.

21. Felder RM. Learning and Teaching Styles in Engineering Education. Engineering Education. 1988;18(7):674-81.
22. Educating the engineer of 2020: Adapting new engineering education to the new century. Washington D.C.: National Academies Press, 2005.
23. How people learn: National Research Council, 1999.

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