AC 2007-785: A WEB-BASED ELECTRONIC BOOK (EBOOK) FOR SOLID MECHANICS

Kurt Gramoll, University of Oklahoma

Kurt Gramoll is the Hughes Centennial Professor of Engineering and Director of the Engineering Media Lab at the University of Oklahoma. He received his B.S. degree in Civil Engineering and M.S. degree in Mechanical Engineering, both from the University of Utah and received his Ph.D. in Engineering Science and Mechanics from Virginia Tech. He has developed and published several CDs and web-based sites for engineering education.

A Web-based Electronic Book (eBook) for Solid Mechanics

Abstract

The use of electronic media has been widely recognized as an effective and efficient tool in delivering course materials. Through electronic media, interactive and visual appealing media such as texts, animations, graphics, simulations and sounds can be incorporated in the illustrations of engineering theories and concepts. The motivation of developing such media is to promote students' interest in engineering education and perhaps have a positive impact on the quality of education. This paper presents an eBook in solid mechanics that is delivered via the web (www.ecourses.ou.edu). The online eBook is intended to cover materials for a typical introductory solid mechanics (i.e. mechanics of materials or strength of materials) course. It can be used as a stand-alone tool for distance learning or as a supplementary material for traditional classes. In addition, this eBook is designed and developed such that it could be a just-in-time learning tool for students and engineers who would like to learn or review a specific topic in solid mechanics. The mechanics eBook has been used in actual courses as the primary text for the course and has been reviewed by several engineering professionals. The eBook is an on going development and new sections are being added as needed.

The solid mechanics eBook currently consists of over 30 modules. Each module is further divided into parts that include case introduction, theory, case solution, examples and simulation. A concerted effort has been invested in relating the theory to real world engineering applications through the case studies. Applications from different disciplines (e.g., daily experiences, mechanical, aerospace, and civil engineering applications) are included. The design approach of this eBook is to capture students' interest by first presenting a case study. The theories and concepts necessary for the students to solve the specific case study are then covered, and followed by a complete solution for the case study. Some additional examples are also provided for some sections. The material of this eBook is open for any institution or student to use without cost or condition.

I. Introduction

Electronic media has been widely used in education, particularly in the discipline of engineering where complex and abstract mathematical model or theory can be easily visualized through the use of appealing media such as texts, animations, graphics, simulations and sounds. As such, more educators are now incorporating electronic media in their teaching. However, one obstacle in implementing electronic media for traditional engineering courses is the scarcity of robust and complete solid mechanics course material on the Internet.

Some of the web-based course modules presently available on the web and readily for others to use include prerequisite engineering courses such as Statics[1], Dynamics[2], Thermodynamics[3-4], and Fluids[5]. The trend in utilizing interactive and electronic media in presenting engineering principles has been increasing over the past few years as well. Just to name a few, interactive

CD-based fluid mechanics textbooks include *Multi-Media Fluid Mechanics* by Homsy et al.[6] and *Fluid Mechanics: An Interactive Text* by Liggett and Caughey[7]. On the other hand, comprehensive web-based modules in the area of solid mechanics are relatively scarce. There are supplemental modules, including the award winning MDSolids and MecMovies by Tim Philpot[8-9] and one developed over 10 years ago by the author that was distributed on CD[10]. However, CD distribution has numerous obstacles including cost, computer compatibility, updating and technical support.

In 2001, an NSF-sponsored workshop was held to find ways to improve undergraduate mechanics across the curriculum[11]. One of the discussion topics was the use of multimedia technology to enhance engineering education in general, and fluid mechanics education in particular. The panel suggested initiating and developing a central web site for mechanics where universities, colleges and industries can all share the resources.

Realizing the need for a comprehensive text for solid mechanics in electronic form was, in part, the motivation for the current project to develop a web-based Multimedia Engineering Solid Mechanics eBook (www.eCourses.ou.edu), which is both informative and interactive. The goal is to enhance the learning experience of the student in studying mechanics of materials, and also perhaps attract more students to become enthusiastic in the field of solid mechanics. To encourage using electronic media, the material of this eBook is freely open for any institution or student to use without cost or conditions through the Internet. This eBook can be used as a stand-alone tool for distance learning or for regular classes in which students are expected to go over and review the materials before class on their own. Instructor can then make better use of the class time to engage students in active learning and address any questions students may have had, and hence promoting interaction and discussion in class. In addition, this eBook is designed and developed such that it could be a just-in-time learning tool for students and engineers who would like to learn or review a specific topic in solid mechanics. It can also serve as supplementary material to reinforce the lectures taught in traditional classes.

II. An Overview of the Multimedia Solid Mechanics eBook

Solid Mechanics is encountered frequently in our daily lives, and the study of mechanics is broad, and it involves different engineering disciplines such as the aerospace, biomedical, chemical, civil, environmental, mechanical and petroleum engineering. Hence, a web-based Multimedia Engineering Solid Mechanics eBook has been developed at the University of Oklahoma to cover solid mechanics at the introductory level for cross-disciplines, and it is intended to be a shared instructional resource among universities and colleges. The Multimedia Engineering Solid Mechanics eBook consists of over 30 sections or modules with each module divided into 3 to 4 different parts: case introduction, theory, case solution, and examples. In each module, the theory part covers a particular topic in solid mechanics. The modules are grouped into 10 different sections according to the topics, and they are accessible through the menu bar on the left from the main page (Figure 1). In addition, tables for solid structural properties, section properties, beam deflection tables, common mathematical formulae, and unit conversion tables are included in the appendices. As seen from the main page, all students need to view this eBook is a browser with Shockwave plug-in, which is commonly used and can be downloaded freely through the Internet.

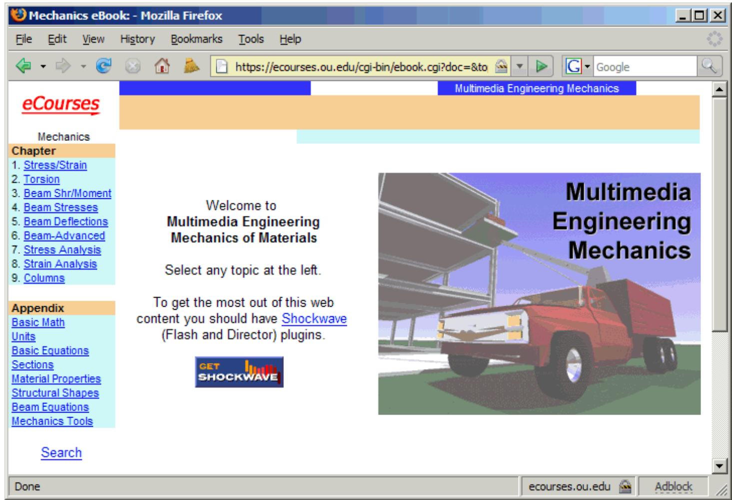

Figure 1. Main page of the Multimedia Engineering Solid Mechanics eBook

The contents of solid mechanics at the introductory level have not changed for several generations. Therefore, the contents covered in this Multimedia Engineering Solid Mechanics eBook mimic those of traditional and popular textbooks such as Hibbler[12] and Pytel et al.[13] The organization of the eBook content is summarized in Table 1. The emphasis and challenge of the present project is to find ways to present the materials with the aids of multimedia technology. The design approach of this eBook is to capture students' interest by first presenting a case study. The theories and concepts necessary for the students to solve the specific case study are then covered, and followed by a complete solution for the case study. A concerted effort has been invested in finding case studies related to real world engineering applications. This is to ensure that the students are trained to have an intuition on how to tackle real world problems by making adequate assumptions and hence reduce the complexity of the problem.

Table 1. Table of Contents for the Solid Mechanics eBook

Chapter 1: Normal Stress and Strain Sec 1.1: Normal Stress Sec 1.2: Shear and Bearing Stress Sec 1.3: Normal Strain Sec 1.4: Hooke's Law Sec 1.5: Thermal Effects Sec 1.6: Indeterminate Axial Structures	Chapter 6: Beam-Advanced Topics Sec 6.1: Composite Beams Sec 6.2: Reinforced Concrete Beams Sec 6.3: Unsymmetric Beams Sec 6.4: Shear Flow in Thin Beams Sec 6.5: Shear Center
Chapter 2: Torsion Sec 2.1: Circular Bars and Shafts Sec 2.2: Non-uniform and Indeterminate Torsion Sec 2.3: Thin-walled Tubes Chapter 3: Shear and Moment in Beams Sec 3.1: Shear and Moment in Beams Sec 3.2: Shear and Moment Diagrams Sec 3.3: Moving Loads	Chapter 7: Stress Analysis Sec 7.1: Plane Stress Sec 7.2: Principal Stresses and Maximum Shear Stresses Sec 7.3: Mohr's Circle for Stress Sec 7.4: Failure Sec 7.5: 3D Stress State Sec 7.6: Pressure Vessels Sec 7.7: Stress Concentrations
Chapter 4: Beam Stresses Sec 4.1: Bending Strain and Stress Sec 4.2: Beam Design Sec 4.3: Shear Stress Sec 4.4: Built-up Beams Sec 4.5: Combined Loads	Chapter 8: Strain Analysis Sec 8.1: Plane Strain Sec 8.2: Mohr's Circle for Strain Sec 8.3: Strain Gages
Chapter 5: Beam Deflections Sec 5.1: Integration of Moment Equation Sec 5.2: Integration of Load Equation Sec 5.3: Method of Superposition Sec 5.4: Indeterminate Beams Sec 5.5: Discontinuity Equation Sec 5.6: Moment-Area Method	Chapter 9: Columns Sec 9.1: Basic Columns Sec 9.2: Fixed Columns Sec 9.3: Eccentric Loads and Secant Formula Sec 9.4: Column Design

In a recent study, St. Clair and Baker[14] compared 10 different software programs/course modules delivering the contents in Statics. Based on their assessment report, they concluded that the Multimedia Engineering Statics eBook fulfills majority of the evaluation criteria. The design philosophy of Multimedia Engineering Solid Mechanics eBook is essentially the same as that of Multimedia Engineering Statics eBook, hence it has most of the important pedagogical features that St. Clair and Baker identified. The eBook was also tested with an actual online class where the only textbook was the Statics eBook[15]. Some of the key features of Multimedia Engineering Solid Mechanics eBook include user-friendly navigation, attractive interface, theory related to real world applications, visual appealing multimedia technology usage, and constructive simulation. Detailed discussion of these features is given in the subsequent section.

Based on past experiences, both the Multimedia Engineering Statics and Dynamics eBook have gained favorable responses from the students. The implementation of such an eBook in course delivery is particularly convenient for students at the University of Oklahoma since all engineering students have laptop computers with wireless network connections. Most classrooms, lecture halls, libraries and student union are now equipped with wireless connection, and students can have instant access to the course materials practically from anytime and anywhere on campus.

III. Features of the Multimedia Engineering Solid Mechanics eBook

(a) Case Introduction

At the beginning of each module, a case study is first introduced and presented to the students. The case studies selected are closely related to real world engineering applications, and they are from different disciplines (e.g., daily experiences, mechanical, aerospace and civil engineering applications). Assumptions needed to solve the case study are clearly stated as they serve as a hint to the students on setting up the problem. For example, Figure 2 shows a case study for the "Beam Design" module. The case study chosen for this particular module is related to bending stresses for a beam used to hold water in a tank. This application comes directly from a real water tank used to contain small whales and dolphins at Sea World in San Diego.

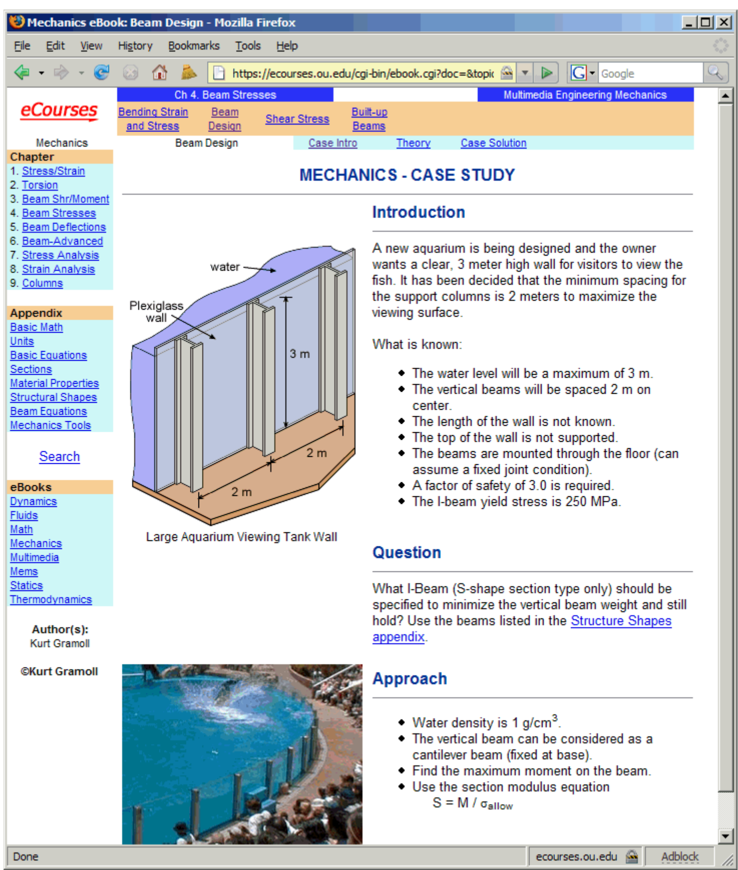

Figure 2. A typical case study interface

(b) Theory

After introducing the case study, the theory required for solving the case study is presented. The theory part has extensive use of the interactive media such as texts, graphics, sounds, and animations for illustration purposes. This is extremely beneficial to engineering education as complex models and abstract concepts or theories can be illustrated easily using these better visualization techniques. Figure 3 shows a typical theory page. Torsion of circular bars is the topic of discussion in this particular module. As seen in the figure, texts, diagrams, pictures, animations and equations are all incorporated to illustrate the theory. Although each module of this eBook is written and developed as a stand-alone module, links are provided to direct students to a particular module of the eBook if they choose to review a certain topic. The materials covered in the theory section are kept in a concise and simple fashion.

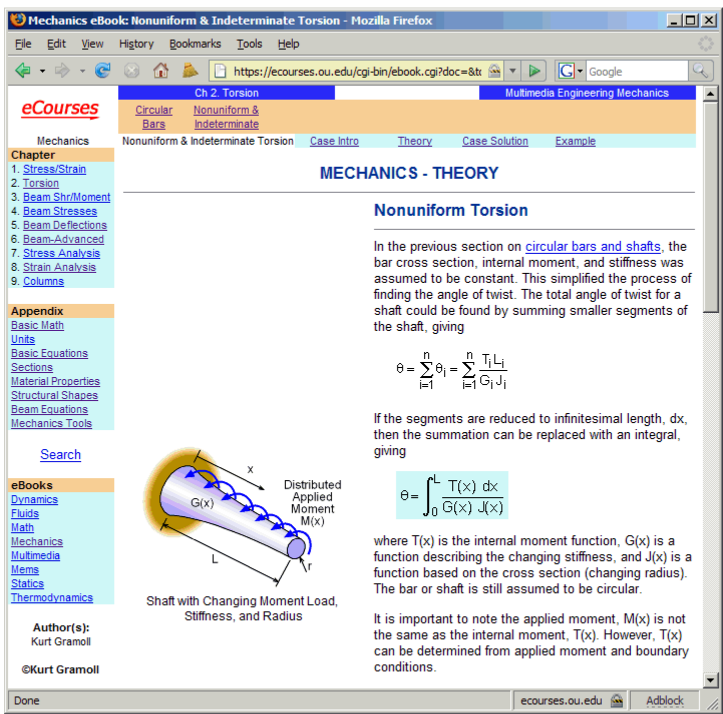

Figure 3. A typical theory interface

Animations are used throughout the eBook to help presenting a case study or illustrate a certain concept. Take the animations as shown in Figure 4 for example, which help illustrate problem solution steps, bearing stresses on bolts and tri-axial compression of cubes. All movies and animations included in the eBook are created using Adobe Flash. The Flash movie files are small in file size since they are vector-based graphics (i.e., less than 100 kb with narrations) and can be downloaded easily through the Internet.

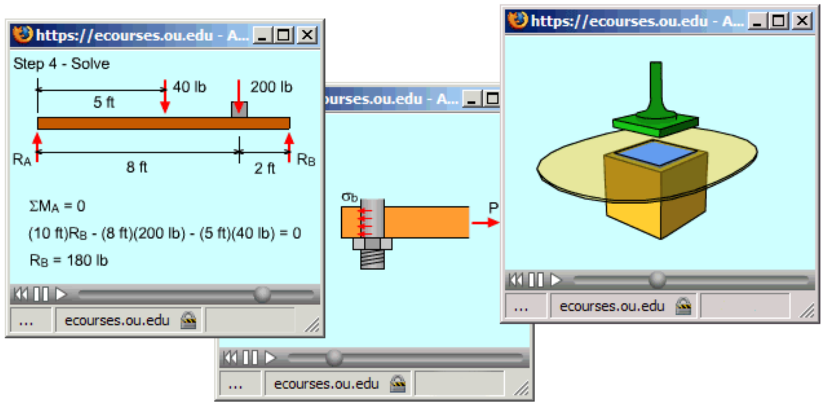

Figure 4. A typical movie/animation interface

Another advantage of electronic education media, which is often overlooked and under-appreciated, is the unlimited use of color. In fact, it presents a major advantage that electronic media has to offer over traditional textbook. Most paper textbooks have limited use of color in their illustrations in order to minimize the publication cost. Using electronic media, on the other hand, charts and diagrams are brought to life with the color usage (Figure 5). Many of the diagrams are vector-based graphics and they can be enlarged to see the details.

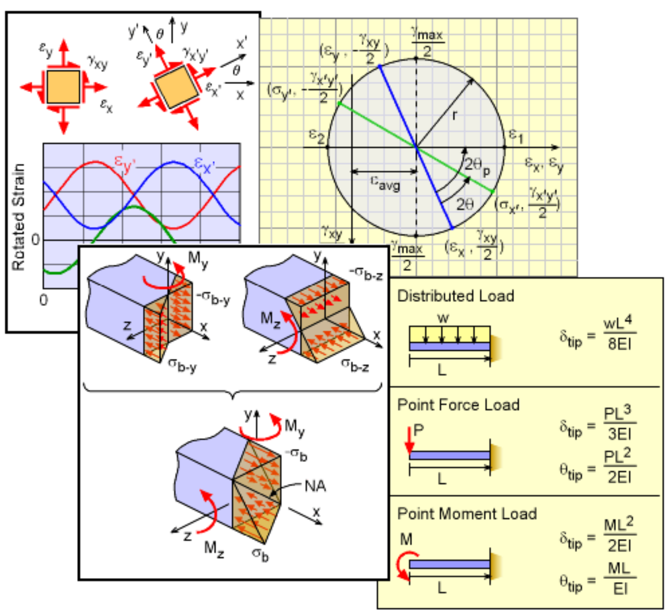

Figure 5. Different charts and diagrams

(c) Case Solutions

Once the materials required for the students to solve a case study are covered in the theory section, a complete detailed solution is given for that particular case study. To improve student's problem solving skills, a systematic approach with step-by-step solution procedure is given here.

A typical case solution page is shown in Figure 6. In this particular solution page, students will learn how to determine the bending stress due to a roof load on a basic T-beam.

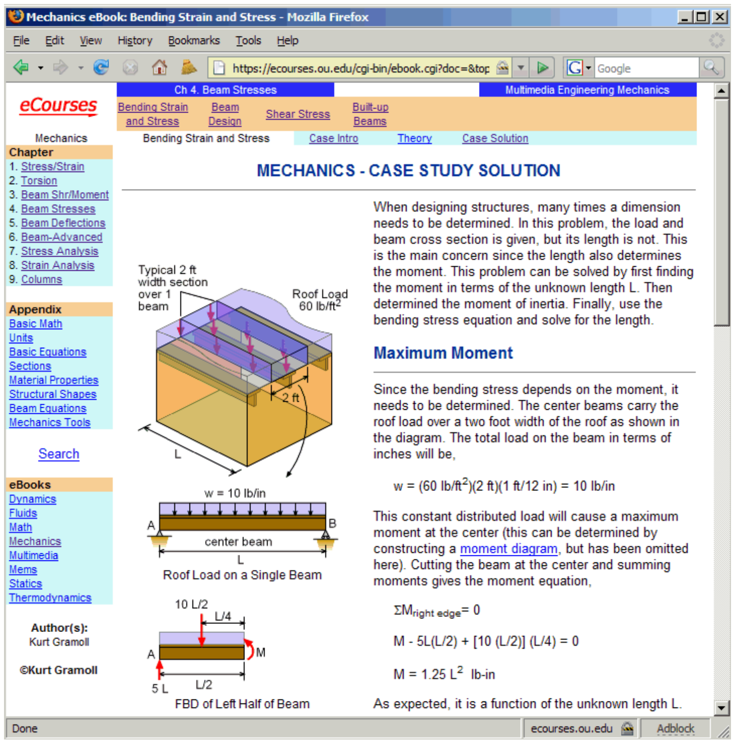

Figure 6. A typical solutions interface

<u>(d) Simulation</u>

One unique feature that electronic media technology has to offer is the use of interactive simulations. Various simulation tools are included to engage students in constructive learning. Students are allowed to adjust several parameters of a problem and immediately observe how these changes will affect the outcome of the results. Two simulation examples, Beam Simulation Tool and Shear Flow Simulation Tool are shown in Figure 7a and 7b. The eBook has others, including Mohr's circle, Beam Stress Tool, and Centroid/Area/Moment Inertia Tool.

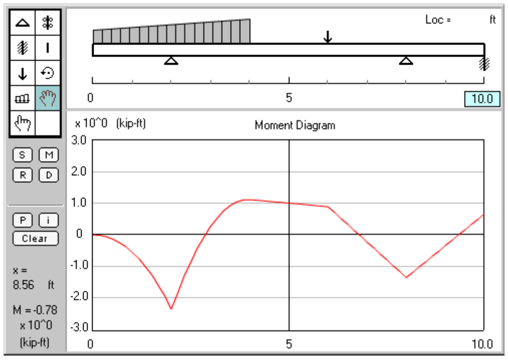

Fig 7a. Beam Simulation Tool

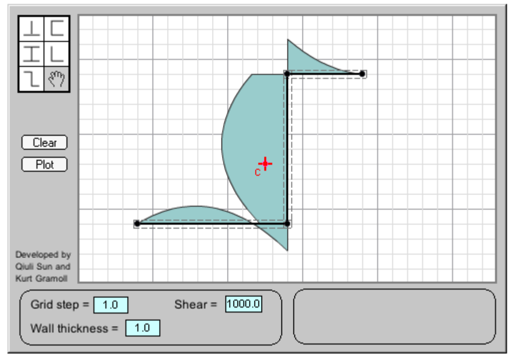

Fig 7b. Shear Flow Simulation Tool

The Beam Simulation Tool shown in Figure 7a is a comprehensive beam analysis program that produces shear, moment, deflection and rotation for most common loading and boundary conditions. The user interface is designed to be simple and easy to understand. The tool bar allows students to place and move three types of loads; point force, point moment and distributed force load. The location and value of each load can be moved and edited. Also, three types of boundary conditions can be applied at any location, including pin, fixed, and roller. These load and boundary condition types cover over 90% of typical solid mechanics problems. The units can be set to either SI or US.

The Shear Flow Simulation Tool allows the user to construct various basic beam cross sections that are common in structures. The cross section can be modified (some restriction exist) by moving the vertex points of the beam cross section. The shear flow is determined by clicking on the plot button. The numerical value of the shear flow at any location is given by moving the mouse over that location.

Simulations such as these provide an active learning environment to the students. All simulations are developed using Adobe (previously known as Macromedia) Director and are saved as shockwave format for web publication. No special software or user permissions are needed for these tools other than the free Shockwave plugin needs to be installed.

V. Implementation and Development

The Solid Mechanics eBook has been used as the main text for the author's solid mechanics class in the Fall 2006. The eBook was integrated into the online learning environment that included all homework problems and online lectures[16]. The current version of the eBook does not have a listing of homework problems since the problems are integrated into the course management system at www.eCourses.ou.edu. The course management system allows the problems to be submitted through a web page and graded automatically. The problem solutions are released after the homework is due through the web site.

The students in the class also had the option to use any of the many mechanics of materials textbooks. Both the web site and another textbook were allowed to be used on exams. Approximately half the students in the class choose to purchase a traditional printed textbook in addition to the online Solid Mechanics eBook.

The students indicated through informal and formal surveys that they liked the eBook due to it being free (saved students over $100 if they choose not to purchase a textbook), always available, extensive reference material in the appendixes, and simulation tools. Another surprising reason for the student liking the eBook was its hyper links to background material throughout the text. These links included material found in other eBooks, such as Statics or Dynamics. Currently, there are seven eBooks available at www.eCourses.ou.edu, Statics, Dynamics, Fluid Dynamics, Math, Thermodynamics, Multimedia and now Solid Mechanics.

The mechanics eBook has been used by other institutions and is open to any one through the Internet (no log-in required). Daily page views (not "hits") for just the Solid Mechanics eBook was over hundred throughout the Fall 2006 semester. Furhermore, currently Google search for "mechanics ebook" ranks it first from nearly one million results. This is a strong indication that it is widely used both at the University of Oklahoma and around the world.

All material in the eBook was develop by the author using basic electronic media tools including DreamWeaver (HTML editor), Flash (2D animation and simulation tool), MathType (equation editor), Carrara (3D animation), PhotoShop (photo editing), and Freehand (2D drawing tool). The total cost for these software tools are below $1,000 (academic pricing). The main cost in developing the material, like any textbook, is the time invested by the author. In general, each module required about 40 hours of development time. This included the time to create all graphics. It should be noted that the author is not a graphic artist, but with the modern graphic software tools listed above, even an engineer, like the author, can create excellent diagram-type graphics. To avoid any copyright issues, all photos were also taken by the author.

V. Summary

A web-based Multimedia Engineering Solid Mechanics eBook has been developed with an extensive use of interactive media. This eBook can be used as a stand-alone tool for distance learning, just-in-time learning tool for review purposes, or as supplementary materials for traditional classes. This eBook is intended to be a shared instructional resource, and it is freely open for any institution or student to use without cost or conditions.

VI. Acknowledgment

The author gratefully acknowledge the support of this work from the National Science Foundation through Grant DUE CCLI EMD 0442446, “Enhancing Engineering Mechanics Instruction with Interactive 3D Virtual Models”. The author is indebted to Ms. Mary Kocak (Professor, Pellissippi State Technical Community College) and Ms. Hengzhong Wen (Engineer, JP Kenny Inc) for proof reading the eBook contents and providing constructive suggestions in improving the quality of this eBook.

References

1. Gramoll, K., “Teaching Statics Online with only Electronic Media on Laptop Computers,” Proceedings of the 1999 American Society for Engineering Education Annual Conference & Exposition (CD-ROM), 1999

2. Vikas, Y., Romanello, T. and Gramoll, K., “Teaching Dynamics Online with only Electronic Media on Laptop Computers,” Proceedings of the 2000 American Society for Engineering Education Annual Conference & Exposition (CD-ROM), 2000

3. Ngo, C. C. and Lai, F. C., “An Online Thermodynamics Courseware,” *Computer Applications in Engineering Education*, Vol. 11, pp. 75-82, 2003

4. Huang, Meirong and Kurt Gramoll, “Online Interactive Multimedia for Engineering Thermodynamics,” ASEE Annual Conf. Proc., Salt Lake City, UT, 20-23 Jun 2004

5. Ngo, Chean Chin and Kurt Gramoll, “A Web-based Electronic Book (eBook) for Fluid Mechanics,” ASEE Annual Conf. Proc., Salt Lake City, UT, 20-23 Jun 2004.

6. Homsy, G. M., Aref, H., Breuer, K. S., Hochgreb, S., Koseff, J. R., Munson, B. R., Powell, K. G., Robertson, C. R., and Thoroddsen, S. T., *Multi-Media Fluid Mechanics*, Cambridge University Press, 2000

7. Liggett, J. A. and Caughey, D. A., *Fluid Mechanics: An Interactive Text*, American Society of Civil Engineers Press, 1998

8. Philpot, T., "MDSolids," Introduction to Mechanics of Solids, http://www.mdsolids.com/

9. Philpot, T., "MecMovies," Mechanics of Solids Movies, http://web.umr.edu/~mecmovie/index.html

10. Ramaprasad, S., K.C. Gramoll, R. Kriz and J. Craig, "The Development and Implementation of Interactive Multimedia in Basic Engineering Education Courses," 1st SUCCEED Conf Proc., N.C. State, Raleigh, N.C., March 3-4, 1994

11. Perlin, M., Schultz, W. W., Smith, M. K., and Foss, J. F., “Improving Undergraduate Fluid Mechanics across the Curriculum,” Proceedings of the 2001 American Society for Engineering Education Annual Conference & Exposition (CD-ROM), 2001.

12. Hibbler, R.C., *Mechanics of Materials*, 6th Edition, Pearson Prentice Hall, New Jersey, 2005

13. Pytel, A. and Kiusalaas, J, *Mechanics of Materials*, Brooks/Cole, US, 2003

14. St. Clair, S. W. and Baker, N. C., “Pedagogy and Technology in Statics,” Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition (CD-ROM), 2003

15. Gramoll, Kurt, Wes Hines, and Mary Kocak, "Delivery and Assessment of Teaching Statics over the Internet to Community College Students," ASEE Annual Conf. Proc., Portland, OR, 12-15 Jun 2005

16. Alramahi, Mohammad and Kurt Gramoll, “Online Collaborative Drawing Board for Real-time Student-Instructor Interaction and Lecture Creation,” ASEE Annual Conf. Proc., Salt Lake City, UT, 20-23 Jun 2004