Efficacy of Computer-Aided Instruction in Design of Machine Elements using MATLAB

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I. Introduction

Engineering educators are under considerable pressure to include more and new materials, to accommodate ABET 2000 criteria, and to restructure contents using new approaches and technologies in spite of the reduced total number of credits for graduation. Computer-based instruction (CBI) is one of the effective means to alleviate the pressure by taking advantage of recent information technologies. In a comprehensive review, Kadiyala and Cryes (2001) demonstrated that information technologies could enhance the quality of teaching and learning when devised with sound pedagogy, good match of technology, techniques and objectives.

Fundamental mechanics courses including statics, dynamics, mechanics of materials, and design of machine elements (DME) are typically taught for mechanical and civil engineering students in lecture and discussion format using traditional techniques such as blackboard, overhead transparencies, etc. These courses involve many complicated engineering calculations and analysis procedures, eliciting tedium, complexity, and computational burden. These hamper both students and instructor to efficiently learn and teach several topics in a conventional classroom setting. Though MERLOT search reveals no success, there are some computational tools available for fundamental mechanics course such as StressAlyzer (Steif 2002), Solid Mechanics Toolbox (Golnaraghi et al. 1999), custom programs in TK-Solver (Bhonsle & Weinman 1999) and MATLAB (Magrab et al. 2000). Most of them, however, are textbook-specific and thus of limited utility. There is a great need for comprehensive and integrated software tools for general use in teaching and learning DME.

II. The Mechanical Design Toolbox

The Mechanical Design Toolbox (MDT), a collection of individual mechanics analysis and design modules in MATLAB, was developed for CBI in a junior-level DME course at UW-Milwaukee, in an attempt to minimize many trivial and time-consuming activities such as performing repetitive calculations, back solving equations, solving lists, etc. and to solve

complex open-ended design problems for improved understanding on DME. An individual MDT module typically consists of a graphical user interface (GUI) and corresponding GUI control program, and a numerical analysis routine. The GUI accepts input parameters from the input area using textboxes, menus, lists, checkboxes, and other GUI's (Fig. 1a), receives user commands via pushbuttons in the command area (Fig. 1a), and displays results into graphic windows and textboxes in the output area (Fig. 1b). The GUI control program checks the validity of the input parameters and converts them into internal parameters for subsequent design calculation in the numerical analysis routine.

The MDT has evolved over many years through continuous revision of the existing modules and addition of new modules. Currently, the MDT has mechanics analysis modules for unit conversion, material parameter selection, beam shear force and bending moment diagram analysis, deflection analysis, Mohr circle analysis, moment of inertia analysis, static and fatigue failure analysis, concentric and eccentric buckling analysis, and Hertz contact and lubrication analysis. The design modules were developed for design of fasteners, power screws, shafts, springs, pressure vessels, and bearings.

(a)   **(b)**
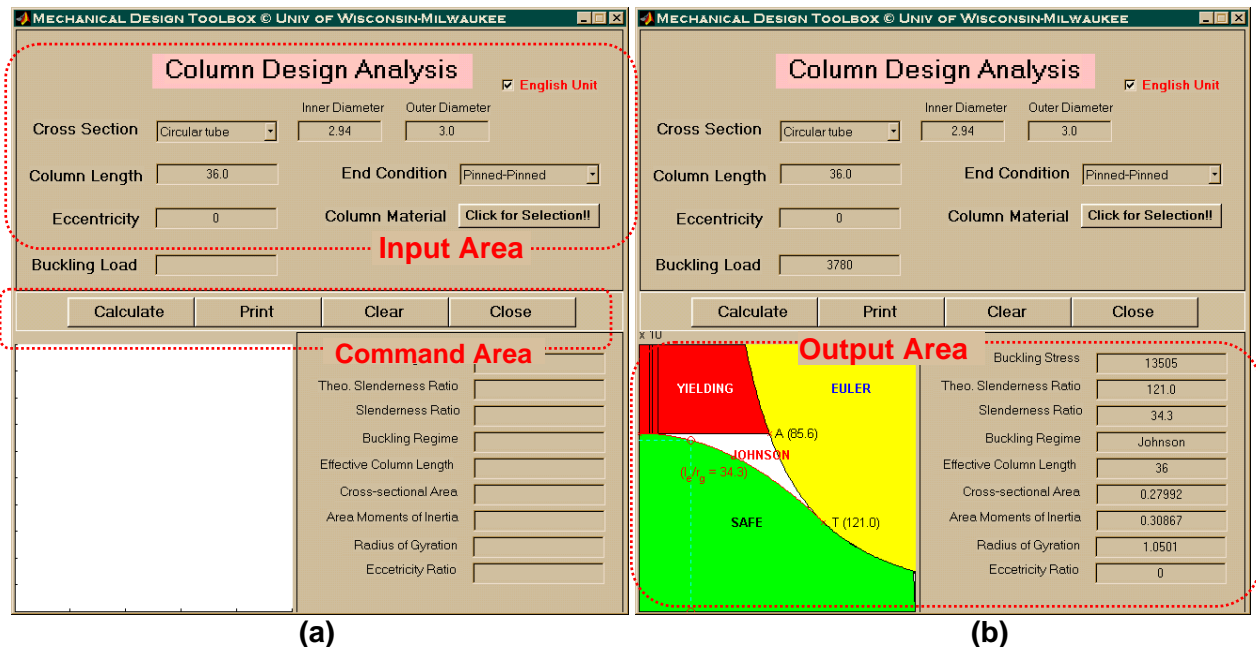
Figure 1. Column design module (Column Tool) in the Mechanical Design Toolbox using MATLAB GUI for solving the example problem under concentric buckling mode.

Development of the MDT using MATLAB is a meritorious choice for many reasons. MATLAB is a programmable numerical analysis and simulation package. Its versatile computational power and portability with other numerous toolboxes have lead to wide use among universities and industry (Hanselman & Littlefield 2001). Using GUI controls with MATLAB results in tools that are very intuitive. These tools provide an interactive learning environment that allows users to immediately see the impact of various design changes. Examples of successful tools of this type can be found in the controls area (MathWorks 1999, Garcia & Heck 1999, Watkins & Mitchell 2000).

III. Evaluation of The MDT in a Classroom Setting

The DME course at UW-Milwaukee is a four-credit required course with two 75-minute lectures and a two-hour discussion per week. Two separate semesters, Spring 2002 and Spring 2003, were taken into account for evaluation of the MDT in terms of homework and exam scores. The former semester (Spring 2002) was taught in the original format, whereas in the latter semester (Spring 2003) the MDT was used during the lectures and discussion sections, and its usage was required for the twelve homework assignments. Same sets of homework assignments and exams (two midterm and one final written exams) with exactly the same questions were given to both groups of students. Though different graduate teaching assistants graded the homework assignments, the same instructor graded the exams with the same grading criteria. The statistical comparisons were made using the effect size and independent t-tests at the level of significance of $p=0.05$. The effect size (ES) is defined as the difference between the mean scores of two groups divided by the standard deviation of the control group (Kadiyala & Crynes 2000). An ES of 0.3 in a typical study is considered a moderate but significant effect (Kulik & Kulik 1999).

Twenty-four and twenty-five mechanical engineering seniors signed up for the course in each semesters, respectively. More students tended to submit the homework assignments when the use of MDT was required. There were 18 no submissions of homework assignments from 8 individual students in the latter semester, whereas 28 no submissions from 12 individual students in the former semester. Four homework assignment scores, ES less than -0.3, demonstrated reduction of the scores with the use of MDT. This is attributable to different graders and different grading criteria that the solutions using the MDT were also part of the grade in the latter semester. However, the exam scores demonstrated statistically significant improvements (Fig. 2; ES>0.9 and p<0.001). Subsequently, the class average of the weighted

total grades was significantly improved from 69.1 (S.D.=11.9) to 85.1 (S.D.=10.8) (p=0.00001) when MDT was used.
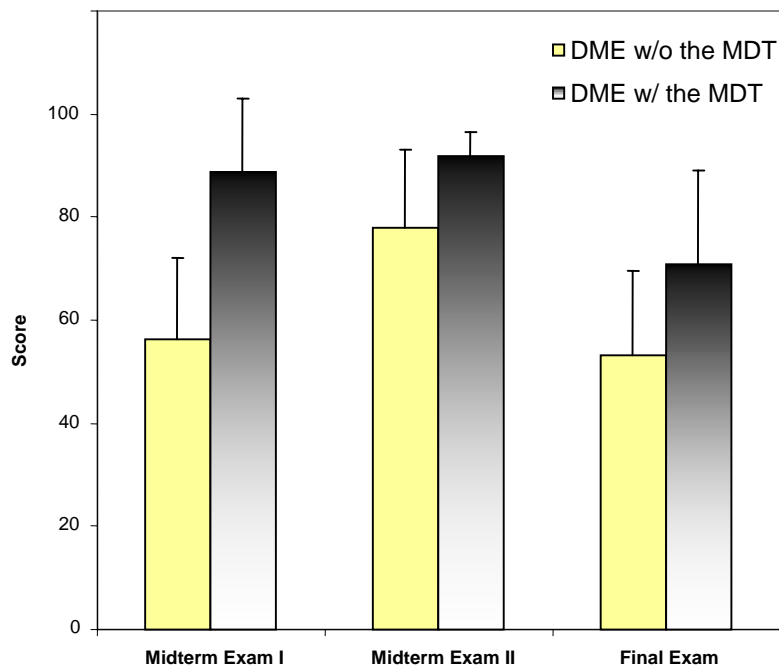
Figure 2. Comparison of exam scores from two separate semesters without and with the use of the MDT in the DME class. The exam scores were significantly different (p<0.00001).

III. CONCLUSIONS

Using MDT can help teaching and learning DME in many ways. Other than apparent benefits of less computational burden and tedium and additional validation tools for the hand calculations, subjective comments from students and instructor's observations indicated that the students could gain an systematic understanding on required design parameters and their mutual effects through various comparative design analyses with "what-if" scenarios. It was suggested that the MDT might potentially lead the students to more problem-based learning and creative design experience. Thus, the MDT is expected to replace and/or complement the traditional blackboard and note-taking paradigm into a multimedia interactive teaching and learning of DME.

IV. REFERENCES

- Bhonsle SR, Weinman KJ (1999) "Mathematical modeling for design of machine components", Prentice-Hall, Upper Saddle River, NJ, pp. 1-5.

- Garcia RC, Heck BH (1999) "An interactive tool for classical control design education," Proceedings of the American Control Conference, San Diego, CA, June 1999, pp. 1460-1464.

- Golnaraghi MF, Boulahbal D, Leask RL (1999) "Solving solid mechanics problems with MATALB® 5", Prentice-Hall, Upper Saddle River, NJ.

- Hanselman D, Littlefield B (2001) "Mastering MATLAB 6", Prentice-Hall, Upper Saddle River, NJ.

- Kadiyala M and Crynes BL (2000) "A Review of Literature on Effectiveness of Use of Information Technology in Education," J of Engineering Education 89:177-184.

- Kulik CL and Kulik J (1991) "Effectiveness of Computer-Based Instructions: An Updated Analysis," Computers in Human Behavior 7:75-94.

- Magrab EB (2000) "An Engineer's guide to MATLAB®", Prentice-Hall, Upper Saddle River, NJ.

- Steif PS (2002) "StressAlyzer", http://www.me.cmu.edu/stressalyzer/.

- The Mathworks (1999) "Control System Toolbox User's Guide," Natick, MA: The Mathworks, Inc.

- Watkins J, Mitchell E (2000) "A MATLAB graphical user interface for linear quadratic control design," Proceedings of the ASEE/IEEE Frontiers in Education Conference, Kansas City, MO, October 2000, pp. F4E7-F4E10.