TEACHING ENGINEERING SUBJECTS USING MATLAB

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Abstract

A required course on programming in MATLAB has been included in the undergraduate programs at Ariel University Center of Samaria since 2000. In the Department of Civil Engineering, students attend a one-semester course in MATLAB in the first year of the program. The course syllabus includes 26 hours of lectures and 26 hours of tutorials. The students learn elementary mathematical commands, functions for vector and matrix operations, logic operators, methods for solving systems of linear equations, graphics, symbolic operations, input-output functions, and other operations. In the MATLAB course, which is taught by a faculty member of the department, students master the methodology of using MATLAB for solving real engineering problems. Throughout their undergraduate studies, students apply their skills in programming to topics related to structural engineering subjects. MATLAB has proved itself to be a very effective tool in the educational process because it offers a simple and powerful tool for analyzing and visualizing results of numerical simulations and measurements. Its universality allows easy understanding of complicated processes in different fields of engineering, forming a basis for greater success in education.
Key words: *MATLAB, engineering education, programming skills*.

Introduction

The use of highly advanced technologies in instruction frequently creates a false “hi-tech” atmosphere in the classroom: Not all sophisticated technological applications promote learning. In their historical review of technological applications in education and their impact on learning, Kent and McNergney (1999) argued that new technologies must be accompanied by instructional methods and pedagogy which are specifically adapted to the technologies in use.

For solving any engineering problem using existing software, efficient algorithms should be implemented in a programming language. Case studies motivate the development of efficient algorithms that involve, in some cases, transformation of the problem from its initial formulation into a more tractable form (Kent & McNergney, 1999). MATLAB is the software that is often chosen for teaching engineering students because of its ubiquitous use in engineering studies and practice. Moreover, it is widely available to students on school networks and through inexpensive educational versions, making MATLAB a great tool for teaching scientific computation (Kiusalaas, 2005).

Adawi (2003) notes that students will lose motivation to use the software tools unless the MATLAB programming is integrated into the curriculum. The use of MATLAB in the engineering curriculum is today widespread. Many engineering textbooks offer MATLAB exercises. There is also an extensive literature on the use of MATLAB to augment engineering courses.

Fangohr (2004) described and compared programming languages C, MATLAB, and Python as teaching languages for engineering students. Two distinct phases in the process of converting a given problem into a computer program that could provide a solution were distinguished: finding an algorithmic solution and implementing this in a particular programming language. It was suggested that a well-structured teaching language with a clear and intuitive syntax allows students to express their algorithms quickly. It was found that MATLAB is much better suited than C to this task but the best choice in terms of clarity and functionality of the language is offered by Python.

Taking a "teach-a-language" approach using MATLAB, it is possible to teach general-purpose language skills and concepts and take advantage of its computational/graphical capabilities (Azemi & Pauley, 2008). By teaching MATLAB, teachers are able to discuss more advanced engineering and mathematical problems in a short period of time, a goal which cannot be accomplished with general-purpose programming languages. It was concluded that since MATLAB is an integrated part of many advanced engineering courses and students' early exposure to this software is beneficial.

Kezunovic et al. (2004) developed a set of MATLAB tools to demonstrate issues in power engineering. These tools consist of pre-built simulations with graphical user interfaces that allow the students to vary system parameters and observe behavior. Gomez-Alfageme et al. (2004) employ a similar approach to augmenting an acoustical engineering course to allow the students to easily synthesize acoustic arrays and plot their behavior.

Carreras & Snider (1998) described an interactive educational tool developed for teaching engineering students complex analysis. This tool focuses on the graphic representation of complex arithmetic operations and the images of complex domains. Visualization was used in a graduate engineering analysis course to provide students with a better understanding and professors with a more stimulating lecture tool. It was suggested that visualization can be of assistance in engineering design in areas where conformal mapping is a useful tool (such as airfoils or waveguides).

Purdue University teaches introductory engineering skills to more than 1,600 first-year students annually using MATLAB, http://www.mathworks.com/company/user_stories/userstory7097.html. By combining introduction to engineering fundamentals with computer tools, the program encourages students to work effectively in technical teams while learning to translate engineering problems into mathematical models. Students learn to implement solution algorithms using MATLAB. It provides them with the skills they need to confidently pursue their engineering career. Using MATLAB rather than C or FORTRAN, students can reduce their coding time by at least 2/3, which gives them more time to focus on solving problems. Because MATLAB is taught to all first-year engineering students, senior faculty have no need to spend precious time getting students up to speed on how to open the program and use the fundamental syntax.

Georgia Tech adopted MATLAB as the foundation for Computing for Engineers, http://www.mathworks.com/company/user_stories/userstory12611.html. This course is required for all Georgia Tech engineering students and is now a pre-requisite for many advanced level courses. In senior-level courses in structural analysis, students use MATLAB to create sophisticated graphical applications.

Teaching computer programming and engineering concepts to first-year students using MATLAB is also implemented at Northeastern University, http://www.mathworks.com/company/user_stories/userstory2359.html. MATLAB provides hands-on experience with testing and measurement instrumentation, and allows students to avoid the multi-step process of saving acquired data to a file and then reading it. Students experience real-world laboratory effects, such as noise, sampling artifacts, and thresh holding techniques. They practice reconciling real data with theory and inferring simple mathematical models from measurement data. Undergraduates are asked to think like engineers by making realistic trade-offs between experimental accuracy and measurement time. Students like using MATLAB along with stepper motors and transducers to show how the experiments are related to real-world problems and to our majors.

Johansson et al. (1998) describe a set of MATLAB programs to assist students in an introductory control class to experiment with linear systems analysis and design techniques. The success reported for these tools suggests that they are significant enhancements to the curriculum.

Yaz & Asemi (1995) describe the use of MATLAB in a nonlinear systems analysis course. They observed improved student understanding of the course material and increased student interest in the subject. It was reported that among the significant challenges to integrating the software tools are ensuring that students have sufficient access to the software, teaching the students to use the software without interfering with the course material, and making the use of MATLAB integral to the course.

MATLAB has been incorporated in undergraduate and graduate curriculums of engineering studies in other universities (i.e., RWTH Aachen University in Germany, http://www.mathworks.com/company/user_stories/userstory20508.htm, Technische Universiteit Eindhoven in Netherlands, http://www.mathworks.com/company/user_stories/userstory19919.html, University of Melbourne in Australia, http://www.mathworks.com/company/user_stories/userstory19859.html. MATLAB enables the teachers to gradually develop more complex coursework and to integrate elements of multiple engineering disciplines into the curriculum at undergraduate and graduate levels.

Pedagogical Aspects

All undergraduate programs can be divided into disciplinary courses and service courses. For example, the main theoretical disciplinary courses in civil engineering, that form a basis for deep understanding of specific engineering topics, include engineering mechanics, strength of materials, structural analysis, and structural dynamics. Service courses, such as descriptive geometry, engineering graphics, mathematics, physics, programming, and statistics, are obligatory for successful understanding of the above mentioned disciplinary courses.

In social studies programs, methodology courses such as guided reading or courses on research methodology provide students the necessary knowledge required for proper understanding of basic subjects in each department.

Service courses are typically taught by lecturers and tutors who do not necessarily have specialized knowledge in each specific program. For example, courses in programming for engineering students are taught by instructors who specialize in computing or mathematics. As a result, engineering students who take such service course acquire only general skills, as the lectures and practical exercises in these courses are not focused on the problems that are related to their engineering specialty. For students, a major issue is discovering the interconnectedness of knowledge (Biggs, 1999). This concept is relevant for the design of service courses, where knowledge may be presented to students out of the context of the important constructs of their core discipline (Gordon et al., 2007).

Dividing subjects to disciplinary (core) and service (methodology) courses is an artificial division that is generally based on economical considerations. However, if first-year students fail to learn how to implement the proper methods and skills to solve real problems related to their core subjects, they cannot apply the general knowledge acquired in the service courses as it is desired. Hence, from the authors' viewpoint, faculty members from the core department should teach service courses, because only instructors who have specialized in a core discipline knows the most useful and effective method to apply the general knowledge (i.e., statistics, mathematics, physics, programming) to the students' specific discipline.

New technologies do not fully utilize their unique pedagogical and technological advantages unless institutions embark on an institutional or systemic development program that gives equal weight to pedagogy and technology, and ensures that the process trickles down to individual faculty. Several studies highlight the crucial role of instructors in the adoption process of new online technologies in academic teaching (Elstein, 2004). Studies in USA have shown that only 2 out of 10 US college instructors make regular use of computers in their teaching (Leung & Ivy, 2003). Apparently, instructors are also the weakest link in the process of integrating innovative technology in academic institutions (Collis & Moonen, 2001; Hagner & Schneebeck, 2001; Leung & Ivy, 2003; Elstein, 2004).

Using MATLAB for Teaching Structural Engineering

According to the undergraduate curriculum in structural engineering at the Ariel University Center in Samaria, students must study engineering mechanics as a pre-requisite or co-requisite for "Programming in MATLAB". Hence the following problems are recommended as exercises in the MATLAB course:

- Addition and subtraction of forces;
- Calculation of force's moment at a specific point;
- Finding a resultant force and resultant moment of a plane or space forces system;
- Calculation of support reactions in beams;
- Calculation of support reactions in frames using matrix solution of a system of linear equilibrium equations;
- Calculation and plotting the shear forces' and bending moments' diagrams using forces' equilibrium and differential relations;
- Calculation of cross-section area properties for sections with different geometry;

Mastering the use of MATLAB to solve real engineering problems entails:

- Identification of physical processes;
- Understanding relations between actions and reactions as well as their interpretation using mathematical operations;
- Understanding relations between physical and mathematical models as well as the meaning of equations and their solution;
- Using graphical abilities of MATLAB to gain a deep understanding of the solution and its physical matter.

Students continue to apply MATLAB to solve complicated engineering problems in other core courses. In "Structural Analysis 1", MATLAB is used to calculate support reactions and internal forces, to draw influence lines in statically determined structures, and to obtain matrix solutions of flexibility method's equations. In "Structural Analysis 2", MATLAB is applied to calculate and plot influence lines in statically undetermined beams using focal points; to obtain matrix solution of stiffness method's equations; to calculate stiffness matrices for elements with variable sections by inversing the flexibility matrix, and for static condensation of stiffness matrices.

Teaching some of the advanced topics in structural engineering is impossible without adequate skills in numerical methods and computers. Incorporating MATLAB software in advanced courses facilitates the teaching process significantly, and yields a much deeper understanding of engineering problems by the undergraduates. In "Computer-based methods in structural analysis", MATLAB is further used for substructuring and considering aligned and elastic supports. In "Structural dynamics", MATLAB is applied for static condensation of stiffness matrices; to calculate eigenvalues and eigenvectors perform modal analyses of free and forced vibrations, identify rigidity and torsion centers, and for numerical linear and nonlinear dynamic time history analysis. MATLAB facilitates students' mastery of modern techniques and approaches to effective structural analysis, and offers a foundation for the development of proper design concepts.

Thus, practicing programming throughout the undergraduate program allows students to acquire proficiency in a methodology of solving a wide variety of engineering problems that cannot be solved by manual calculation. The solutions are discovered by developing, programming, and solving creating corresponding mathematical models using MATLAB software.

Conclusions

As part of the program of the Ariel University Center of Samaria to develop unique pedagogies that gives equal weight to pedagogy and technology, the Faculty of Engineering has attempted to break the artificial distinction between technology and pedagogy by incorporating a typical service course in MATLAB programming more strongly into the undergraduate program, and ensuring that MATLAB skills are taught by instructors from the field of engineering, and students' skills are implemented in the specific context of students disciplinary knowledge.

While the computer will never replace the instructor, instructors who genuinely master new technologies will replace instructors who fail to do so. According to our worldview at the College, mastery entails an intricate intertwining of pedagogy and technology. The MATLAB course in the Department of Civil Engineering at the Ariel University Center is an example of such integration of pedagogy and technology.

Ten years of experience using MATLAB at the department has shown that MATLAB is a very effective instrument in the educational process. It offers a simple and powerful tool for analyzing and visualizing results of numerical simulations and measurements. Its universality allows easy understanding of complicated processes in different fields of engineering, forming a basis for greater success in education.

When students develop corresponding mathematical models and implement original algorithms in MATLAB in different courses throughout the entire course of their undergraduate studies, students gain important experience in solving real and non-standard engineering problems that cannot be solved manually.

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