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Workshops on Fundamental Engineering Skills: A Graduate Student-Led Teaching Initiative

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Workshops on Fundamental Engineering Skills: A Graduate Student-Led Teaching Initiative

1. Introduction

Graduate programs often fund doctoral students while they complete their thesis research. This funding generally takes three forms: fellowships, research assistantships and teaching assistantships. Depending on the discipline, one type of funding may be more prevalent than the others. For instance, graduate students studying English often have teaching assistantships where they are responsible for developing an entire course. Engineering students more often have research assistantships, and available teaching opportunities can be limited to facilitating a laboratory section without developing its content.[1] As a consequence, engineering students can be left without the curriculum development experience necessary to become the next generation of excellent instructors. Some disciplines have recognized the need for graduate student teaching development;[2-4] however, these programs are not widespread.

Undergraduate students in engineering are often required to learn specialized skills such as MATLAB, Mathematica, Excel, SolidWorks, and COMSOL Multiphysics. These skills are indispensible in many areas of engineering, yet students may not receive the instruction necessary to feel confident in their use. While some skills are taught in introductory courses, students may not fully appreciate their utility or extensively use the skills until they are needed later in their coursework. Often, students are expected to learn these skills outside of class; this can be challenging when coupled with similar requirements for other courses. Furthermore, students transferring from other institutions may never receive any introduction to such skills, leaving them at a disadvantage compared to their non-transfer peers.

Supplemental Instruction (SI) in engineering facilitates material assimilation for difficult, "high-risk" classes.[5-8] These programs generally work in collaboration with specific courses to provide opportunities for students to discuss concepts and problems from class. SI facilitators are generally model students who have taken the course,[6] instead of graduate students, and there may not be a need for an entire semester of sessions. Attributes of the SI model, including targeting challenging skills and providing an avenue for voluntary interactive learning, can also be incorporated in a program for graduate student teaching.

To address "high-risk" skills in engineering, interactive workshops provide an attractive opportunity for graduate students to gain curriculum development experience while helping other students become better-equipped engineers. In this paper, we provide an outline and preliminary analysis of our graduate student-led teaching initiative as part of a student chapter of the American Society for Engineering Education (ASEE). The program aims to fill two needs within the engineering community: curriculum development and implementation experience for graduate students, and supplemental instruction on fundamental engineering skills for undergraduates. We present our program as a case study with a description of the program format, list of workshops held, and a discussion of student and instructor outcomes.

2. Workshop Structure

a. Academic advisor consultation

Prior to developing the workshop initiative, we consulted undergraduate academic advisors within the College of Engineering to determine the skills for which supplemental instruction may be advantageous to student success. Suggested topics included: plotting and data analysis in MATLAB and Mathematica, solving linear systems of equations, plotting in Excel, 6-sigma analysis, and solving equations analytically using Mathematica, among others. These suggestions formed the foundation for defining the program, with a mission to fill these apparent gaps in student knowledge.

b. Workshop proposals

To help facilitate development of well-prepared workshops, members interested in creating a new workshop are required to submit a proposal that outlines the workshop's scope, outcomes and prerequisites. This proposal system helps prospective instructors place their workshops into a framework that will be useful when later constructing the details of the workshop content. Proposals are reviewed by the ASEE student chapter executive board, which considers the scope of the material relative to the allotted workshop time, the specific workshop goals and whether there are systematic methods to achieve said goals, and the perceived need of the workshop content. Once a proposal has been reviewed, revised as needed, and accepted, the workshop instructor can fully develop the workshop. To ensure instructors have sufficient time to thoughtfully develop their curriculum, the proposal submission deadline is set multiple weeks before the scheduled workshop. The proposal rubric and a sample proposal are included in the Appendix.

Our proposal system is meant to imitate the process faculty often follow when suggesting a new course in established curricula. It serves to help student instructors clearly define the goals of their workshop and how those goals are to be met. Requiring a definitive workshop framework can also help facilitate efficient workshop development, which may translate to more substantive courses.

c. Practice workshops

Student instructors develop their workshops according to their submitted proposals and the executive board's feedback. To give student instructors an opportunity to implement their workshop prior to the official date, practice workshops are held with members of the ASEE student chapter. During these practice runs, peer participants provide feedback on workshop aspects that may need to be addressed prior to the official workshop, which include, in part, notation consistency, instructional pace, breadth of material, and timing. The practice workshops are held one week prior to the scheduled time of implementation, which ensures there is time to address the concerns of the workshop participants.

Both the instructor and the workshop participants can benefit from these practice workshops. For student instructors, they provide opportunities to speak in front of an audience that is committed to teaching. The audience can see subtleties that may have been overlooked as the instructor was developing the workshop, which when addressed, can enhance the clarity and flow of the workshop. Because the participants are vested in quality teaching, they can be critical of the workshop's presentation and content; ultimately, this can be of great value to the student instructor. For the audience, a practice run gives individuals a chance to critique another instructor's lesson, see which methods are effective and which are not, and discuss the workshop content.

d. Student recruiting and registration

To recruit students, we use the College of Engineering's listing of upcoming events and we send monthly emails to undergraduate academic advisors with descriptions of upcoming workshops. The notifications include a short synopsis of the workshops as well as a link to our website and registration form. The registration form includes demographic information and asks students what they hope to learn from the workshop. Registration is opened a week before the workshop and the instructor may contact the registrants prior to the workshop regarding pre-workshop readings or to remind students of their registration.

e. Workshop environment and execution

Each interactive workshop includes 90 minutes of computer-based instruction. The layout of the room can be seen in Figure 1. The computer lab supports as many as 40 computer stations and can be partitioned for smaller workshops; a large workshop can be divided into smaller audiences to enable separate instructors to hold independent workshops. The room has four quadrants with projection screens facing each quadrant. The instructor is constrained to a single quadrant with an immobile workstation. The instructor's desktop is projected on all the screens to allow students to see the commands and keystrokes used by the instructor. Each student follows the instructor's lead to generate the desired results, making students active participants in their learning.

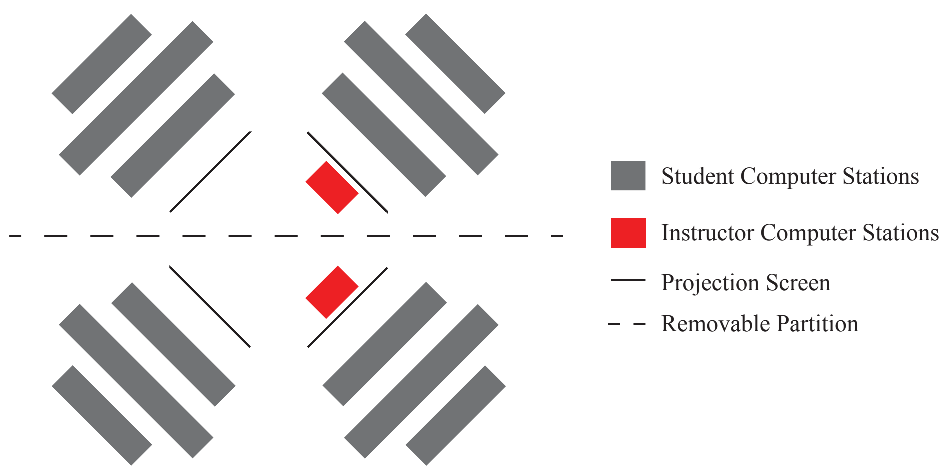

Figure 1: Computer lab layout. Four quadrants of computers face the center of the room. The room can be partitioned into two separate rooms, each with 20 computers and an instructor's station.

f. Roaming assistants

In addition to the instructor, roaming assistants help students during the workshop. These assistants are members of the ASEE student chapter who may be responsible for a different workshop or may want teaching experience but do not have time to develop and implement an entire workshop. In addition to answering individual questions, these assistants provide real-time feedback for the instructor on how the students are managing the workshop's pace. Each quadrant has a roaming instructor, which results in one assistant per approximately ten students.

3. Workshops held to date

a. Workshop content

We held preliminary workshops addressing MATLAB, Mathematica, and Excel skills during the Winter 2013 semester to start initiative development and organization. During the Fall 2013 semester, eight workshops were held covering these programs on Monday nights from 7:00-8:30 PM. The workshops were placed in a rotating schedule: MATLAB #1, Mathematica #1, Excel #1, MATLAB #2, Mathematica #2, Excel #2, MATLAB #3, and Excel #3. Table 1 shows the workshop schedule for the Fall 2013 term and topics covered. To further the program, Winter 2014 workshops augmented these skills to include SolidWorks, Illustrator, Photoshop, Python, LaTeX and presentation skills.

Table 1: List of workshops held during the Fall 2013 semester with the dates and topics covered.

Date	Workshop Title	Topics Covered
9/16/13	**MATLAB:** Introduction	Variable declaration, matrix operations, for loops, if statements, while loops, plotting
9/23/13	**Mathematica:** Introduction	Variable definition, symbolic calculations, list manipulation, use of common Mathematica functions
9/30/13	**Excel:** Advanced Plotting	Importing data, bar graphs, scatter plots, error bars, trend lines, figure formating
10/7/13	**MATLAB:** Ordinary Differential Equations (ODEs)	ode45 solver, first and second order ODEs, coupled systems of ODEs
10/21/13	**Mathematica:** Equation Solving	Algebraic equation solving (Solve and FindRoot), analytical and numerical equation solving (DSolve and NDSolve), parameter manipulation and dynamic plotting of solutions
10/28/13	**Excel:** Macros I	Recording keystrokes to create macros, text editor error correction and addition of functions
11/4/13	**MATLAB:** Advanced Plotting	Plot handles, 3D plots, subplots
11/11/13	**Excel:** Macros II	Writing macros in visual basic for applications (VBA) using Excel editor: for loops, if statements, cell handles

The initial computer program choice and workshop content were driven by the perceived needs of undergraduate students as discussed with academic advisors. Each of the initial programs (MATLAB, Mathematica and Excel) is extensively used in engineering. Students are introduced to these programs during their introductory engineering courses, which are not necessarily taken by transfer students, and they may not ever be explicitly taught in upper-level courses. Additionally, we use participant polls to determine other skills students would like to see taught. Polls from the Fall 2013 semester were used to structure the Winter 2014 semester to include SolidWorks, Illustrator, Photoshop, LaTeX, and Python.

b. Workshop development flexibility

The flexibility of both the program and the instructors provides ample opportunities to work individually or in a group to develop workshop curriculum. For example, a single instructor developed the MATLAB ordinary differential equations workshop, while two instructors wrote the MATLAB plotting workshop. For the plotting workshop, the instructors collaborated to determine the topics to be covered (handles, 3D plotting and subplots), but each instructor developed his own course. In this way, the instructors could generate coherent workshops while individually developing their own workshop materials. The Excel Macros workshops, in contrast to these other approaches, were developed by two instructors who worked together to define a workshop series that included an introductory session and a more advanced session. This flexibility in time commitment and responsibility helps enable instructors with various time constraints to participate in developing and implementing workshops. If members are interested in teaching but not developing an entire workshop they can instead become roaming assistants.

4. Workshop Evaluation

Participant responses to post-workshop surveys, as well as focus groups held for participants and instructors, suggest the workshop series has been an asset for all involved. Although the current datasets from post-workshop surveys are limited, trends in the results indicate approval of our program by participants. A sample workshop survey is included in the Appendix.

a. Student participant demographics and survey results

Participants from 15+ departments have attended workshops with Industrial and Operations Engineering (IOE), Civil and Environmental Engineering (CEE), Mechanical Engineering (ME), and Electrical Engineering and Computer Science (EECS) accounting for approximately 50% of the total respondents (N=157). These students represented all academic levels where juniors and graduate students accounted for the largest participant percentages, 37% and 30%, respectively.

Although our intent is to cater to undergraduate needs, where we believe we can make the most significant contribution to our local engineering community, recruiting solely undergraduate students to attend workshops is challenging. Figure 2 shows the percentage of undergraduate student attendance over time. The figure is organized according to the material being covered. The trial workshops from Winter 2013 were publicized through undergraduate academic advisors, which resulted in undergraduate audiences only. Because of the increased number of workshops during the subsequent semester, individual emails to academic advisors were not feasible. Instead, college-wide publicity was utilized, which increased workshop visibility to graduate students who have also found the topics of interest. Consequently, a smaller proportion of undergraduate students attended workshops during the Fall 2013 semester; in one case 80% of the participants were graduate students. Because the needs of graduate students and undergraduate students may be in dissonance, focusing on advertising through undergraduate program coordinators was once again employed during the Winter 2014 semester. Thus, we sent monthly workshop summaries through undergraduate coordinators to target the undergraduate population in addition to the College of Engineering event calendar. As a result, the proportion of undergraduate students attending workshops increased.

Although the visibility of workshops to graduate students likely accounts for much of the increase in graduate student attendance, other factors including more complex topics and increased undergraduate commitments toward the end of the semester may also have contributed to the decrease in the proportion of undergraduate student attendance. Interestingly, despite targeting a smaller population by advertising predominantly through undergraduate program coordinators, the number of participants has not been affected, perhaps due to students receiving a direct email from their program coordinators.

Transfer students have accounted for an average of 40% of the participants for the last six workshops, with an error of the mean of 8%. The College of Engineering reports the student population includes 6% transfer students, which is well below the workshop attendance. Although this represents a limited dataset, it suggests that transfer students, in particular, find the topics relevant to their needs. A recent study indicated that transfer students are often very

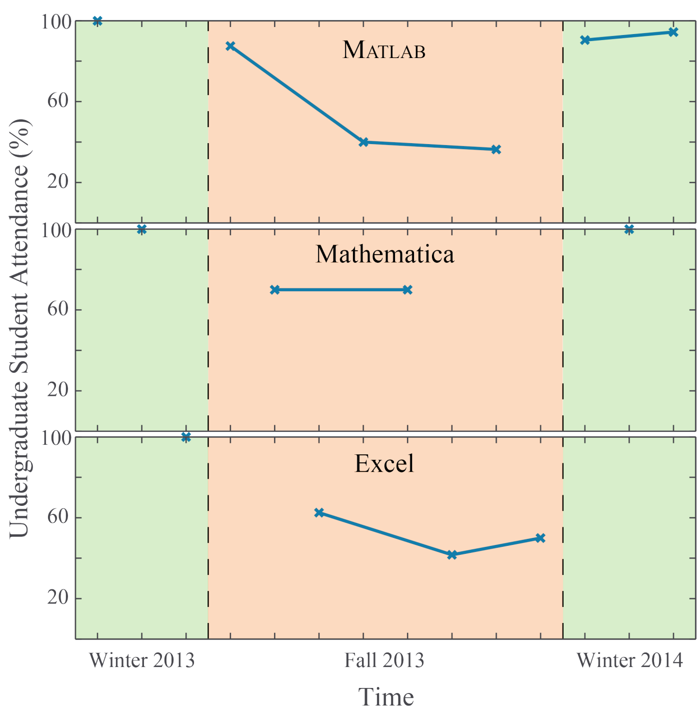

Figure 2: Percentage of undergraduate students attending workshops over the three-semester trial period. The green sections indicate time periods where undergraduate academic advisors were primarily used for advertising. The orange section indicates the semester where only college-wide advertising was utilized.

committed to their discipline, and thus may be more apt to seek opportunities to ensure their success in their chosen discipline.[9] Unfortunately, transfer student specific return-rate data has not been collected to determine what percentage of transfer students are returning for multiple workshops. However, the proportion of transfer students is nonetheless significant and suggests our program is addressing the needs originally established.

The preliminary measure of success for our teaching initiative is based on student satisfaction, where 95±3% (average±error of the mean) of students who completed the survey found the workshops to be worth their time. Furthermore, 95±2.5% of students felt more comfortable with the taught skill after completing the workshop. Although these metrics do not directly indicate the efficacy of the workshops, they suggest that students value them and believe they are benefitting from participating. Student satisfaction and workshop worth may also be inferred from the relatively high percentage of students who attended multiple workshops. Figure 3 shows the percentage of returning students since the program's inception. The maximum returning student rate is 60% with an average of approximately 35±4%. With the exception of the two macro-based Excel workshops, each workshop was independent from previous workshops. Although one would expect a high return rate for this Excel series, which is exhibited in the data, the relatively high average return rate suggests many students value the workshop content and implementation enough to attend subsequent workshops.

b. Student participant focus group

In addition to the survey responses, we held a participant focus group to gain a better understanding of the efficacy of the workshops. The focus group consisted of four students who

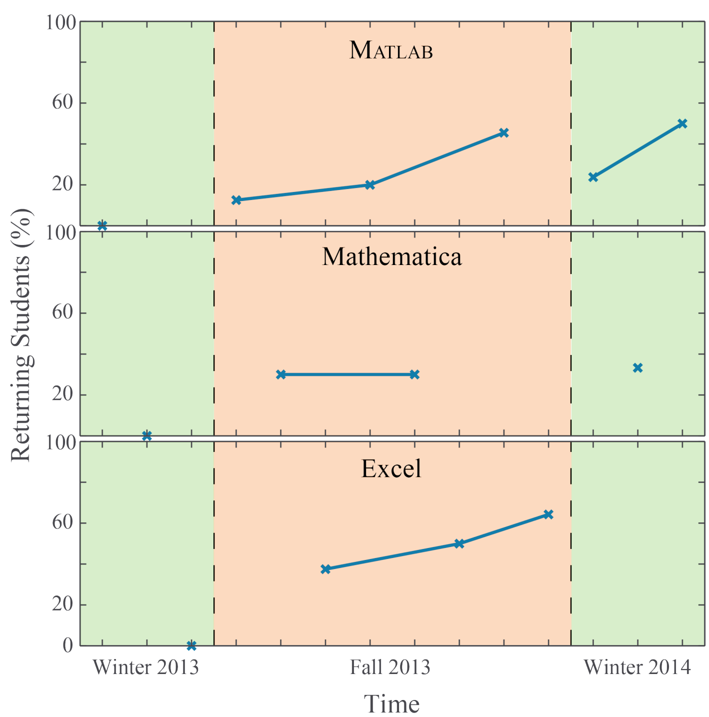

Figure 3: Percentage of returning students for each workshop as a function of time.

had attended one or more workshops since the program's inception. Two of the participants were transfer students who had limited exposure to the topics taught in their respective workshops.

The need for supplemental instruction is recognized. One transfer student indicated, "I need to learn MATLAB for courses next semester and basically throughout [my college career] so that gap is there. The school I used to go to did not teach it [MATLAB]." Another student expressed the need for supplemental instruction from a different perspective:

> *I learned MATLAB in my freshman course called Engineering 101: Introduction to Computer Programming. In that course it was a brief introduction to MATLAB and the course pace was so fast. At that time I was just a freshman so I didn't know what the application of the software was, so it didn't make sense to me to be an expert. But later on in my sophomore course there was a lot of plotting analysis requiring MATLAB, but professors assume you know it (sic).*

To better understand whether students are gaining the intended skill sets from the workshops, we discussed student implementation of concepts learned in the workshops during the focus group. Several MATLAB workshops were well received and students found the content to be useful, illustrated by students' use of the developed MATLAB script files in subsequent homework assignments and reports.

> *I found the plotting workshop extremely helpful. I think of it as a role model because they went through a variety of things covering a lot of aspects. When I do homework … I refer to how it was done in that example. I find it quite useful.*

> *I just had an assignment for my computer class [and] they were talking about MATLAB. I had the MATLAB workshop recently. When I forget something, I pull up the file so I can look up shortcuts [commands].*

Although these are singular instances, they suggest students may be benefitting from attending our workshops. Furthermore, students expressed gratitude and support for our efforts toward helping students gain these skills, which further validates our program.

c. Instructor program evaluation and focus group

Nine instructors have developed and implemented workshops and approximately 15 additional members have contributed as roaming assistants and practice workshop participants. Active participation has increased from two to 20 members since the program was initiated, with members representing academic levels ranging from first year graduate students to postdoctoral scholars. Instructor teaching experience ranges from having no formal instruction experience to having experience teaching an entire course.

A focus group for student instructors was held to gain an understanding of why graduate students are interested in developing workshops and whether the curriculum development experience is meeting their expectations and needs. Four instructors, who were not associated with the program evaluation presented here, participated.

Members participated in the workshop program to gain a better understanding of engineering education research and to gain experience in curriculum development and teaching. One participant stated, "Teaching is something I might want to pursue in the future, and in general this [workshop development] is a great chance to develop skills you wouldn't otherwise have a chance to develop." A second student explained, "I was interested in putting my knowledge into structure and into a structured workshop."

Unlike a standard course where unfinished material can be covered in a subsequent class period, the workshop format forces instructors to ensure completion in a limited time. An instructor explained it as, "You only get 1.5 hours, and this is the only session you have…It's a good balance of straight-forward presenting that also allows students to apply the skills in the same time." Instructors found this useful but not entirely equivalent to entire-course development, where homework can be assigned and content can more easily be adapted to student needs over time.

Both the proposal system and required practice workshops were found to be useful to instructors during curriculum development and implementation. The instructors felt the additional pressure to define their goals and methods early was beneficial to their workshop. One participant expressed, "It was something to get the ball rolling ahead of time and start thinking about things early. I think it worked out well." Furthermore, the practice workshops were found to be effective at discovering where the instruction was unclear. An instructor explained,

> *They were definitely helpful for people to point out A) the issues with my code [content]… and B) where things get confusing. While you are writing up your notes … it is almost impossible to figure out where things get confusing.*

If a graduate student familiar with a program became confused during a practice workshop, it acted as a clear indication that an inexperienced audience would likely struggle. By addressing these concerns, which were not obvious to the instructor prior to the practice workshop, the instructor could clarify or simplify the content before presenting to an audience with little experience.

Although many aspects of the workshop program were found to be useful to the instructors, the comments received from workshop participant surveys were found to lack actionable feedback. Because the workshops are independent and generally only held once per semester, the large feedback-loop for implementing student advice inhibits improvement of the workshops and instruction. Furthermore, instructors felt that a singular workshop does not provide experience developing an entire course in which themes and foundations are built, as mentioned above. Addressing these concerns may include holding the same workshop several times over the course of the semester and having interested instructors develop a workshop series where themes can be incorporated.

d. Program improvement and future

The workshop format and group of students interested in teaching provide a foundation for expanding the current curriculum development opportunities. We plan to collaborate with a faculty member who relies on a computer-based skill, such as MATLAB, but may not have the class time necessary to teach the skill. This can provide an opportunity to develop a mini-course for further course development experience, which is desired by several of the instructors. We also have established connections with the teaching and instruction center in the College of Engineering, which can provide feedback on instructor teaching. This feedback may be used when applying for academic positions. Furthermore, we have access to equipment that can be used to record the workshops for instructor growth and dissemination of workshop content. By improving and expanding our program in these ways we hope to continue to be a strong asset to the engineering community.

5. Suggestions for starting a similar program

The program's success is dependent on graduate student effort toward program coordination, curriculum development, and workshop advertising. While larger numbers of participants can help in all areas of the initiative, a program can be scaled to the number of available members. With six members, we held three workshops over the course of a semester. Although this was challenging, the workshops were successful and we had time to work out details and overcome difficulties without the pressure of additional workshops. With 20 active participants, approximately 10 of whom are interested in holding workshops, eight workshops per semester with proposal writing and weekly practice are manageable. It is important to open registration early. Confirming registration with students prior to the workshop can help minimize the number of students who register but do not attend. Additionally, undergraduate academic advisors are a strong resource during program planning and development; they work closely with students, can help advertise workshops, and can often suggest other faculty and staff who may have further insight into student needs. With moderate effort, a successful program can be established that garners support from the local engineering community, addresses important needs of graduate students interested in academic careers, and aids students who want to further develop important engineering skills.

6. Conclusion

We have presented our preliminary analysis of our graduate student-led teaching initiative, which provides curriculum development experience for instructors and engineering skills instruction for participants. Of the student participants, 95% have indicated they feel more comfortable with the skills they were taught, and students have used the skills learned in their subsequent coursework. Instructors value the responsibility of developing curriculum and have found that the experience augments their previous teaching experience, where the responsibility of developing the curriculum is valued. With the initial success of the program and its continued development and improvement, we hope to provide meaningful growth opportunities for both graduate student instructors and workshop participants.

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Appendix

Workshop Proposal Rubric

The workshop proposal process is intended to give you the opportunity to put your workshop into a concrete framework with defined tasks. The executive committee reviews proposals and provides feedback on the scope and content of the workshop, which should be addressed prior to workshop development. The proposal should be approximately one page in length and include the 6 elements.

1. Workshop Title

2. When do you hope to hold this workshop?

3. Introduction/Synopsis: Why is this topic of interest to the College of Engineering? What is the overarching theme and main objective of the course? (This will likely be displayed on the website)

4. Description: What is the focus of the workshop, in particular, what topics, concepts, methods, issues, or problems will be covered?

5. Learning Goals: By the end of the workshop, students will know or be able to do what? Use bullet points to emphasize and clarify the scope of the workshop.

6. Prerequisites to the workshop? This is important to ensure students have the necessary preparation to benefit from the proposed workshop.

ASEE Workshop Proposal:
Solving Ordinary Differential Equations (ODEs) in MATLAB

Author, PhD Candidate, Engineering
September 5, 2013

To be held during Fall 2013.

An extremely large number of engineering problems are formulated in the language of differential equations. Examples include everything from electromagnetic equations, to models of flow around an airfoil, to the viscoelastic properties of biological tissues. Often, these problems are extremely complex and require the use of computational tools to solve. MATLAB is one such tool that is widely used by scientists and engineers for this purpose. The goal of this course is to introduce students to various ways of solving ordinary and partial differential equations using MATLAB.

The focus of this course is the implementation of MATLAB differential equation solvers with an emphasis on problem solving. Students will be introduced to common example problems from science and engineering and will work through the process of solving these differential equations using both built-in and custom coded MATLAB tools. Example problems may include:

1. Series RC Circuit (First Order Linear)
2. Predator-Prey Systems for Supply Chains (First Order Nonlinear System)
3. Spring-Mass-Damper Systems (Second Order Linear)

Students will learn how to use built-in MATLAB solvers (such as ode45) to solve mathematical problems with applications in engineering. In doing this, the students will learn not only the implementation but also how to translate mathematical problems into engineering programs. Brief mentions will also be given to concepts such as resonance, phase planes, and convergence.

By the end of the workshop, the students will:

- Understand the concept of numerical integration
- Solve a system of first order nonlinear ODEs using the ode45 function
- Rewrite a second order linear ODE as a system of first order linear ODEs

It will be important that students already be somewhat comfortable with MATLAB. I will assume that they are familiar with basic matrix and element-by-element operations, indexing, and loops. I will also assume that students have some familiarity with differential equations, but all mathematics will be explained before solving.

ASEE Fundamental Engineering Skills Workshop Survey

Demographic Information

(1) What is your area of study?

(2) What is your academic level?

(3) Are you an international student?

(4) Are you a transfer student?

(5) Have you attended a previous ASEE workshop? If so, which one(s)?

(6) Gender Male ◯ Female ◯

Prior Knowledge

(7) Please rank your level of exposure to Mathematica and other skills prior to this workshop.

	No Experience	Little Experience	Moderate Experience	Much Experience	Expert
Overall Mathematica Exposure	◯	◯	◯	◯	◯
Basic Operations	◯	◯	◯	◯	◯
Variable Declaration	◯	◯	◯	◯	◯
Function Declaration	◯	◯	◯	◯	◯
List Manipulation	◯	◯	◯	◯	◯
Equation Solving	◯	◯	◯	◯	◯
Plotting	◯	◯	◯	◯	◯

Quality of Instruction

(8) Which skills (if any) do you wish had been explained more thoroughly?

(9) Do you feel more comfortable using Mathematica?

Yes ◯ No ◯ Not Sure ◯

(10) Please rate the quality of instruction for the following aspects of the workshop.

	Poor	Needs Improvement	Average	Good	Excellent
Basic Operations	◯	◯	◯	◯	◯
Variable Declaration	◯	◯	◯	◯	◯
Function Declaration	◯	◯	◯	◯	◯
List Manipulation	◯	◯	◯	◯	◯
Equation Solving	◯	◯	◯	◯	◯
Plotting	◯	◯	◯	◯	◯

(11) Was the instruction sufficient for you to be able to use the following skills in the future?

	Yes	No
Basic Operations	◯	◯
Variable Declaration	◯	◯
Function Declaration	◯	◯
List Manipulation	◯	◯
Equation Solving	◯	◯
Plotting	◯	◯

General Feedback

(12) Was this workshop worth your time?

(13) What other topics in Mathematica would you like to see?

(14) What other Fundamental Engineering Skills Workshops would you like to see?

Please let us know if there are other concerns you have. Expand on any of the answers you feel is necessary. We want these workshops to be as useful as possible, so your feedback is greatly appreciated.