WIP: Introducing MATLAB-Based Instruction and Learning in the Creativity Thread of a Novel Integrated Approach to ECE Education

Prof. Branislav M. Notaros, Colorado State University

Branislav M. Notaros is Professor and University Distinguished Teaching Scholar in the Department of Electrical and Computer Engineering at Colorado State University, where he also is Director of Electromagnetics Laboratory. His research publications in computational and applied electromagnetics include more than 180 journal and conference papers. He is the author of textbooks Electromagnetics (2010) and MATLAB-Based Electromagnetics (2013), both with Pearson Prentice Hall, as well as Conceptual Electromagnetics (2016) with CRC Press (in print). He was the recipient of the 1999 IEE Marconi Premium, 2005 IEEE Microwave Prize, IEEE Fellow Award (2016), 2005 UMass Dartmouth Scholar of the Year Award, 2012 Colorado State University System Board of Governors Excellence in Undergraduate Teaching Award, 2012 IEEE Region 5 Outstanding Engineering Educator Award, 2014 Carnegie Foundation and CASE USPOY Colorado Professor of the Year Award, 2015 ASEE ECE Distinguished Educator Award, 2015 IEEE Undergraduate Teaching Award, and many other research and teaching/education awards. (for more info, see: www.engr.colostate.edu/˜notaros)

Mr. Ryan McCullough, Colorado State University

Ryan McCullough is a B.S./M.S. student in Electrical Engineering at Colorado State University. He currently has a B.Ed. from the University of Toledo and worked as a teacher for five years before returning to get a degree in electrical engineering in 2014. He is working as a research assistant in both engineering education and MRI RF coil design.

Sanja B. Manic, Colorado State University

Sanja graduated with bachelor's degree from the University of Belgrade, Serbia in 2010, and is currently a graduate student at Colorado State University. Her interests are Numerical methods in Applied Electromagnetics and Antenna design.

Prof. Anthony A. Maciejewski, Colorado State University

Anthony A. Maciejewski received the BS, MS, and PhD degrees in electrical engineering from Ohio State University, Columbus in 1982, 1984, and 1987, respectively. From 1988 to 2001, he was a professor of electrical and computer engineering at Purdue University, West Lafayette. He is currently a professor and head of the Department of Electrical and Computer Engineering at Colorado State University. He is a fellow of IEEE. A complete vita is available at: http://www.engr.colostate.edu/ ˜aam.

WIP: Introducing MATLAB-Based Instruction and Learning in the Creativity Thread of a Novel Integrated Approach to ECE Education

Branislav M. Notaroš, Ryan McCullough, Sanja B. Manić, and Anthony A. Maciejewski
Colorado State University, Electrical & Computer Engineering Department, Fort Collins, CO
notaros@colostate.edu

I. Introduction and Literature Review

Funded by the National Science Foundation to revolutionize engineering and computer science education and departments, through a five-year Revolutionizing Engineering Departments (RED) grant received in 2015, a diverse team of educators in the Department of Electrical and Computer Engineering (ECE) at Colorado State University (CSU) has been implementing changes that reimagine the roles of the faculty, moving away from teaching courses in isolation to an integrated, collaborative structure[1,2]. Key faculty leaders are assigned as "Thread Champions" to interweave Foundations, Creativity, and Professional Formation threads throughout the program, while working with fellow faculty to continue fostering deep knowledge of the discipline and with "Integration Specialists" to synthesize content and illustrate how fundamental concepts are interrelated. These efforts span the entire undergraduate experience, with special attention to the critical technical core of the junior year. This paper focuses on the junior year and the Creativity thread, which is intended to integrate research, design, and optimization tools throughout the undergraduate experience, with an aim toward real-world engineering applications.

As one of the junior year courses, electromagnetics has become one of the focuses of the RED project. It has been noted by several researchers[3-6] that students have an opinion that introductory electromagnetics is a difficult subject, and teachers also find it a difficult subject to teach. They attribute the difficulty to three main factors: 1) the use of vector mathematics which some students can view as rather abstract, 2) introductory classes frequently only cover very idealized situations which do not have true physical applications, and 3) realistic examples in a laboratory setting are difficult to create. Dinov, Sanchez, and Christou[7] also point out that classes which rely heavily on mathematics tend to miss other learning modalities such as visual and active learning. The use of technology can mitigate some of these issues as it can allow for visualization of abstract and mathematical concepts. This also brings in the possibility for design work, a core aspect of the Creativity thread within the RED project, in a way that was not possible through traditional methods.

Within the Creativity thread of the RED project, we consider MATLAB as one of the most essential tools that all ECE students and future engineers should be able to use effectively. MATLAB® (by MathWorks, Inc.) is chosen not only for its very high quality and versatility, but because it represents a generally accepted standard in science and engineering education worldwide.

This work in progress paper presents inclusion of MATLAB-based instruction and learning in the electromagnetics course and learning studio modules (LSMs) of the RED project, where the students are implementing the core LSM concepts they learned into a "virtual electromagnetics testbed" using MATLAB, as part of the Creativity thread. The students are taught "hands on" electromagnetics through a unique and comprehensive collection of MATLAB computer exercises and projects.

Although the use of computer software to aid student learning in electromagnetics has expanded in recent years, it is not widespread yet and is not universally implemented. Also, when computer software is used, MATLAB is not always the program of choice. Finally, when MATLAB has been chosen, the instructors most often have created a GUI[9,10] or some similar interface which the students interact with as opposed to creating their own program. As we note in the following section, this is not as conducive to student learning.

The principal novelty of our approach is introduction of MATLAB programming of electromagnetics – done by students – in junior electromagnetics ECE classes, as opposed to just passive demonstrations to students or their interactive use of available MATLAB tools (codes) for computation and visualization in electromagnetics. Another contribution is constituted by the context of enhancing students' MATLAB skills through electromagnetics for the Creativity Thread of a novel integrated approach to ECE education, the skills to be used in other courses and topics, as well as in knowledge integration activities across courses and the curriculum.

In addition, some examples of the most important pedagogical features of MATLAB related to the instruction and learning of electromagnetic fields and other ECE topics are its abilities to manipulate and visualize vectors and spatially distributed physical quantities, numerically solve problems, and use symbolic programming to reinforce analytical solutions. Some examples of the problems given in the Creativity Thread MATLAB assignments in the electromagnetics class associated with these abilities are presented and discussed in this paper.

II. Methods and Implementation

The MATLAB exercises and projects for the electromagnetics course were created and chosen by the instructor of the course to best support the electromagnetics LSMs and the RED project as a whole[11]. The instructor also authored the textbook used for the course[12], and, as such, was able to choose MATLAB exercises which fluently supported the traditional course content.

Essentially, the students are learning MATLAB in the context of electromagnetics and learning electromagnetics in the context of MATLAB. Moreover, in our opinion and experience, including MATLAB programming actively challenges and involves the student, providing additional, prolonged educational benefits as compared to a passive computer demonstration. This is consistent with the observations by both Hoole[3] and Hoburg[8]: The mere use of computers

does not enhance learning skills; it is when students develop their own programs or general purpose software that arouses curiosity and allows them to try out many possibilities freely, that they learn the most. Example Problems 1 and 2 – given in Table I and Figs. 1 and 2 – show how some of the MATLAB problems encourage students to think about how small changes to the

Table I: Example Problems 1-3 from the Creativity Thread MATLAB assignments in the electromagnetics class.

Example Problem Number	MATLAB Problem Statement
1	MATLAB function quiver is used for visualization of field vectors in space. Input data are coordinates of nodes in a mesh in a Cartesian coordinate system and intensities of field components at the nodes. Implement quiver to visualize the electric field distribution due to a uniform straight line charge of finite length l and total charge Q placed along the x-axis in free space. Although the analytical solution is available in this case, given by $\mathbf{E} = \frac{Q}{4\pi\varepsilon_0 ld}[(\cos\theta_2 - \cos\theta_1)\hat{\mathbf{x}} + (\sin\theta_2 - \sin\theta_1)\hat{\mathbf{y}}]$ for the situation shown in Fig. 1, the electric field vector at each node of the mesh should be computed by vector numerical integration of elementary fields due to equivalent point charges along the line representing short segments into which the line is subdivided. With such an integration (superposition) procedure, this MATLAB program may be applicable, with minor modifications, to many similar and more complex charge distributions, where the analytical expression for electric field components is not available or is difficult to find. Output from the MATLAB code is shown in Fig. 2.
2	Repeat the previous MATLAB exercise but for three equal point charges Q residing at vertices of an equilateral triangle of side a in free space.
3	Write a program in MATLAB that uses [previously created programs] and calculates and plots the electric force on a point charge due to N other point charges in free space. The input to the program consists of N, coordinates of charge points, and charges Q_1, Q_2, . . ., Q_N, as well as coordinates and charge of the point charge on which the force is evaluated. Then use this code to plot the force on one of three equal point charges at vertices of an arbitrary triangle. Output from the MATLAB code is shown in Fig. 3.

MATLAB program can lead to vastly different results. The results from these examples also show the power of MATLAB to visualize vectors, vector math, and spatially distributed quantities, a key component to help students learn. Example Problem 3, presented in Table I and

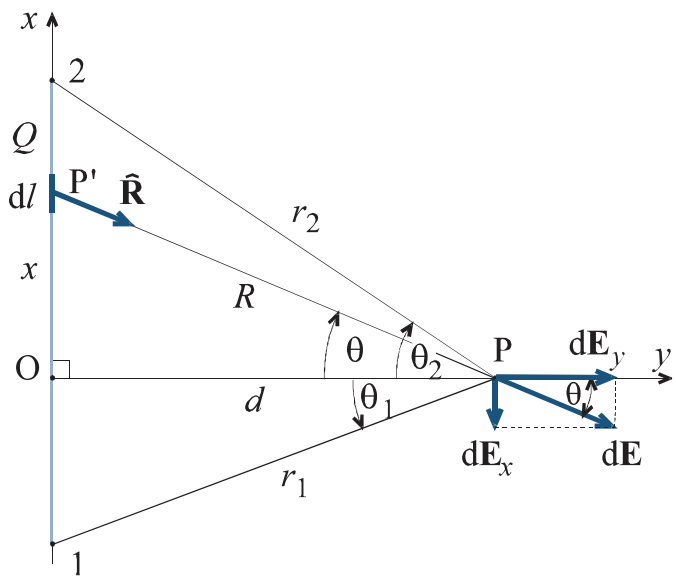

Fig. 1. Geometry for Example Problem 1 in Table I.

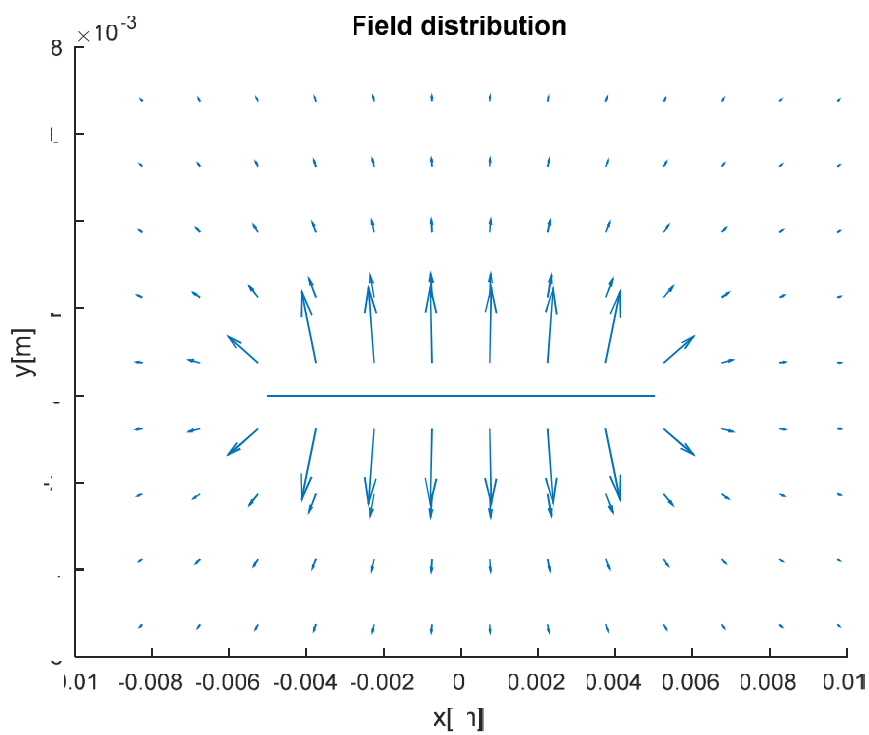

Fig. 2. Graphical output from MATLAB code for Example Problem 1 in Table I, for the following input: Line length in cm: 1; Total charge in nC: 1.

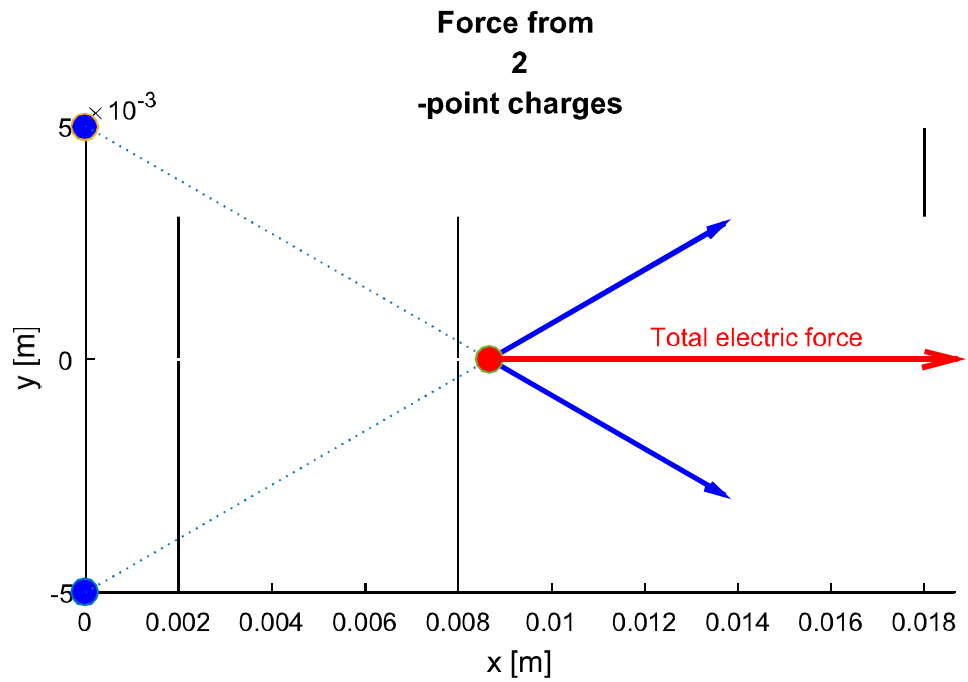

Fig. 3. Graphical output from MATLAB code for Example Problem 3 in Table I, for an adopted position of charges.

Fig. 3, also shows various vector visualization questions and MATLAB programming tasks given to the students.

In "Creativity" class sessions, students are given MATLAB tutorials, with ample discussions of approaches, programming strategies, MATLAB syntax and formalities, and alternatives. This is followed by comprehensive and rather challenging multi-week homework assignments of MATLAB problems and projects in electromagnetics. In addition, students are specifically asked to redo some of their conventional "by hand" computational problems they had for homework now using MATLAB and to thus experience firsthand the power and utility of MATLAB-based numerical and symbolic analysis and computation. An example of a MATLAB problem that requires the students to compare the MATLAB solution to their "by hand" solution is included as Example Problem 4, given in Table II and Fig. 4. In general, solving the problems and studying the topics both analytically and using MATLAB is most beneficial. Further, Figs. 5 and 6 show some other example results from the MATLAB assignments illustrating the power of MATLAB computation and visualization in electromagnetics.

III. Preliminary Results and Discussion

Due to many changes associated with the RED project in the junior year of the electrical engineering program at CSU in the Fall of 2016, we decided that there would be simply too

much work for the students if they had additional MATLAB homework project assignments every week or every other week on top of everything else required of them due to these changes. As such, the electromagnetics instructor only gave two separate large multi-week MATLAB assignments and these were not mandatory but were offered as extra course credit. With this situation in mind, it might not be appropriate to do a quantitative analysis of how these assignments affected the students' grades. Instead, the students who chose to complete the MATLAB assignments were asked to provide comments on the potential effects of MATLAB exercises on (i) understanding of electromagnetic field theory, examples, and problems and (ii) their knowledge of and skills in MATLAB use and programming, that could also potentially be used in other courses in the curriculum and beyond. The comments were voluntary and anonymous.

Table II: Example Problem 4 from the Creativity Thread MATLAB assignments in the electromagnetics class.

Example Problem Number	MATLAB Problem Statement	Related Classical Problem (book Problem 1.49)
4	Redo Problem 1.49 from the book but now using MATLAB. In particular, apply the symbolic function for the gradient in cylindrical coordinates, function gradCyl (from a previous MATLAB Exercise), to the expression for V in $$V \approx \frac{p' \cos\phi}{2\pi\varepsilon_0 r}.$$ Output from the MATLAB code: $$\left(\frac{p\ \cos\phi}{2\varepsilon_0 \pi r^2}, \quad 0, \frac{p\ \sin\phi}{2\varepsilon_0 \pi r^2 \sin\theta}\right)$$	For the line electric dipole shown in Fig. 4, obtain the expression for the electric field intensity vector, **E**, from the expression for the electric scalar potential, V, given by $$V \approx \frac{p' \cos\phi}{2\pi\varepsilon_0 r}$$ where p' is the per-unit-length dipole moment.

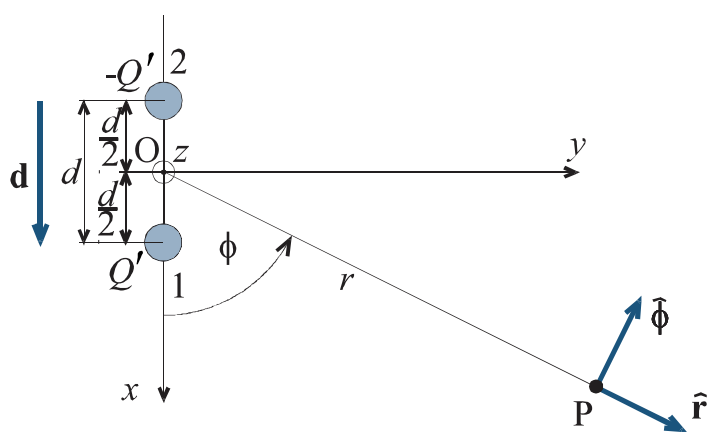

Fig. 4. Geometry (cross section) for Example Problem 4 in Table II.

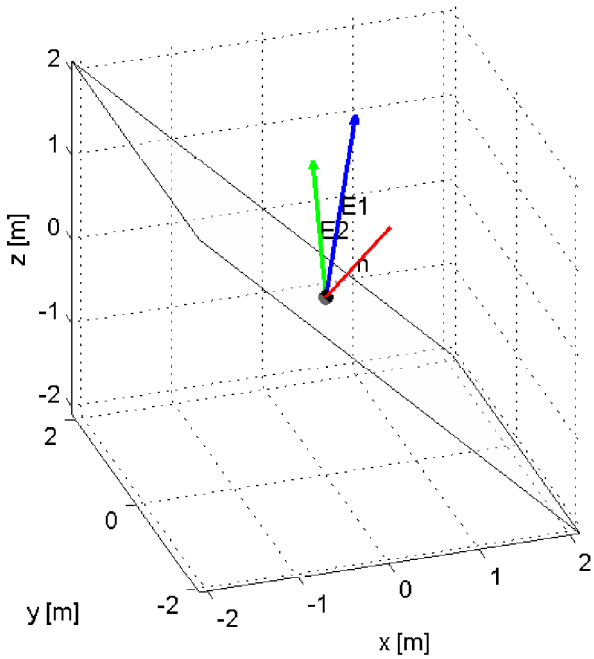

Fig. 5. An example from MATLAB assignment 1 illustrating the power of MATLAB computation and visualization in electromagnetics: MATLAB computation and visualization of dielectric-dielectric vector field boundary conditions for an arbitrarily positioned (oblique) boundary plane between media 1 and 2 with arbitrary permittivities.

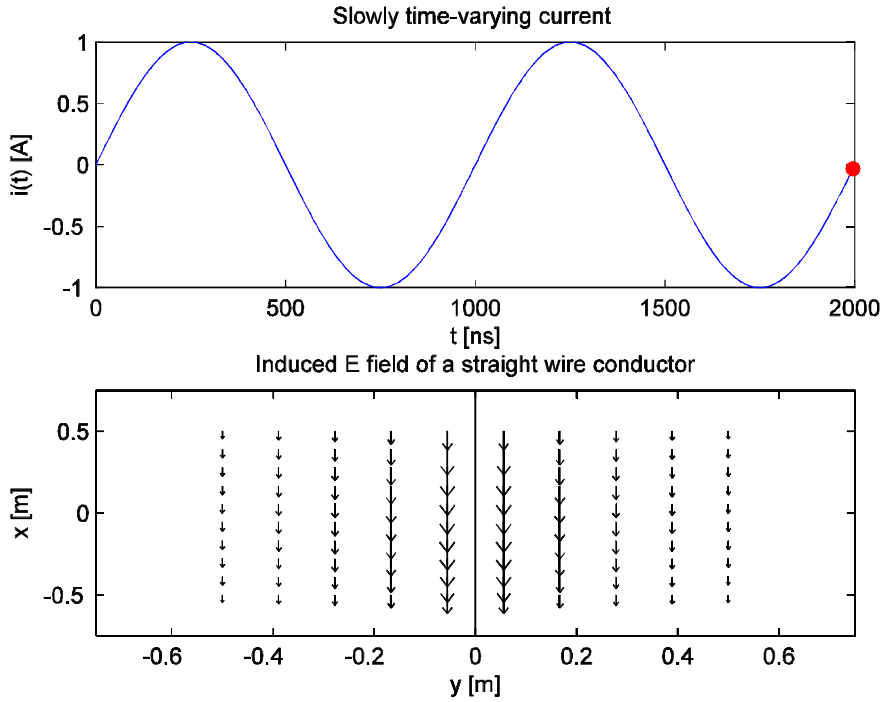

Fig. 6. An example from MATLAB assignment 2: Snapshot of a movie in MATLAB that shows how the induced electric field intensity vector due to a time-harmonic current in a finite straight wire conductor varies in time and space, along (simultaneously) with the temporal variation of the current (two subplots are viewed simultaneously in the movie).

The comments revealed that the students certainly found the project assignments challenging. This is most likely due to the fact that the students have not had a large amount of prior experience with MATLAB. As one student explains it, "I am a fan of MatLab. However, throughout the 2 and 1/2 years with the ECE department here at Colorado State University, there have been a handful of situation where MatLab is used...However, the situations where MatLab is used are few and far between at best. This causes a huge headache...Whenever something comes up that we are required to use MatLab, we have to teach ourselves everything that we may have known at some point along the way. Also there has never been any kind of formal training to use the program. So you're left to flounder with what little knowledge you have picked up along the way." Also, from another student, "If I knew anything about programming or about MATLAB I would have really enjoyed this assignment."

Many students acknowledged and appreciated the importance of MATLAB as an essential tool for ECE and the need for gaining or improving MATLAB use and programming familiarity and expertise for students and engineers: "I like what you are trying to do with this project because I do believe that it will be important for all of us to be familiar with MATLAB at some point before we start our careers. I think it was a good call making the assignment extra credit because most of us have very little understanding with MATLAB in the first place." And another student wrote, "I personally think that the Matlab project was a great idea as in industry I used Matlab all of the time."

Some students confirmed that MATLAB exercises helped them develop a stronger intuition and a deeper understanding of electromagnetic field theory, examples, and problems: "Overall I like that you are trying to enhance our knowledge of electromagnetics using MATLAB because I think it's a very important skill to have and it is interesting to see some of the figures and graphs created using MATLAB. It helps visualize how certain changes and other variables affect the output and fields." "I think that this assignment is a really neat way to combine my knowledge of computer programming to a subject that I am not fond of."

On the other hand, many students stated that MATLAB exercises helped them (instead) gain or improve operational knowledge and skills in concepts and techniques of MATLAB use and programming: "How MATLAB is used in the case of this assignment or other ECE MATLAB assignments, has taught me more about MATLAB than the actual MATLAB class did." "It enhances my Matlab programming a lot."

After the students had gained the knowledge and skills in the first MATLAB assignment, the second assignment's comments show that they felt less strongly that the assignment improved their knowledge and skills in MATLAB. However, the students did feel relatively strongly that the exercises did indeed help them gain a stronger intuition and deeper understanding of electromagnetic field theory. This supports the idea that the students likely did not gain the understanding benefit in the first assignment due to a lack of knowledge and skills in the required

software and programming. This will be something to keep in mind for future iterations of this research.

In addition, the student comments need to be viewed and judged also in the context of the entire RED program. This group of students had increased workload through the individual core junior-level electrical engineering courses and their LSMs, the associated knowledge integration modules between the courses, foundations and professionalism sessions, and team activities. Many students found the "extra" MATLAB assignments overwhelming and overly time-demanding in the context of all the other newly established and required course and program components. "I never had a chance to really try all the problems with multiple other time constraints." "I feel this assignment would have been better to assign when time wasn't so constrained. I barely had any time to work on it and even then I felt very rushed."

IV. Conclusions and Future Work

This paper has presented and discussed inclusion of MATLAB-based instruction and learning in the electromagnetics course and learning studio modules within the Creativity thread of the Revolutionizing Engineering Departments project in the ECE Department at Colorado State University. Creativity class sessions were followed by two comprehensive and rather challenging multi-week homework assignments consisting of MATLAB problems and projects in electromagnetics. The assignments did not only ask the students to generate results, figures, and diagrams, play movies and animations, and solve problems in MATLAB using the existing codes but also required them to perform a great deal of their own programming and testing. The goal is to establish and take advantage of a symbiotic relationship between electromagnetics and MATLAB to ultimately aid electromagnetics and ECE instruction and learning.

The students who participated in the MATLAB exercises had mixed opinions about whether it was helpful to their personal understanding and mastery of the material. Overall, however, the students had relatively positive feedback for the assignments given. For example, of the students who commented, 19 of the 28 had positive things to say about the first assignment. The majority of the negative comments all stem from the common lack of background in MATLAB which the students nearly all share. But this exactly is why these MATLAB sessions and assignments were included, through the electromagnetics course, in the Creativity thread of the RED project, to improve students' operational knowledge and skills in concepts and techniques of MATLAB use and programming, which can then be utilized in other courses in the curriculum, as well as in research activities, senior design projects, etc.

Considering the above, this work in progress will continue to be implemented in future courses, but changes will be made to try to improve the program. First, we plan to expand the scope of Creativity MATLAB class sessions and the use of MATLAB to many more topics in electromagnetics classes. MATLAB problems and projects will be integrated into the homework

assignments regularly throughout the semester. Clear goals will be established for each MATLAB problem/project and scaffolding will be used to ensure that students establish a strong base skill in MATLAB while expanding their knowledge of its power and versatility. This does not mean that the initial programs will not be of a high enough order to truly help the students gain a visualization and understanding of electromagnetics. They will simply have to do less programming in the beginning while they build up their skills until they can fully program some simulations and modeling toward the end. Finally, to further assess how our changes will affect the students taking electromagnetics, several measurements will be designed and carried out in the future.

Acknowledgement

This work was supported by the National Science Foundation under grant EEC-1519438. Any opinions expressed in this paper are those of the authors and are not those of the National Science Foundation.

References

1. Chen, T., Maciejewski, A. A., Notaros, B. M., Pezeshki, A., & Reese, M. D. "Mastering the Core Competencies of Electrical Engineering through Knowledge Integration". American Society for Engineering Education. *2016 ASEE Annual Conference Proceedings*, New Orleans, LA.
2. Maciejewski, A. A., Chen, T. W., Byrne, Z. S., de Miranda, M. A., Sample McMeeking, L. B., Notaros, B. M., Pezeshki, A., Roy S., Leland, A. M., Reese, M. D., Rosales, A. H., Siller, T. J., Toftness, R. F., & Notaros, O. "A Holistic Approach to Transforming Undergraduate Electrical Engineering Education". To appear in *IEEE Access*.
3. Hoole, S.R.H. "A Course on Computer Modeling for Second or Third Year Engineering Undergraduates". *IEEE Transactions on Education*, vol. 36, no. 1 (1993) pp79-89.
4. Beker, B., Bailey, D.W., and Cokkinides, G. J. "An Application-Enhanced Approach to Introductory Electromagnetics". *IEEE Transactions on Education*, vol. 41, no. 1 (1998) pp. 31-36.
5. Chetty, M., Hu, S., and Bennett. "An interactive Java-based educational module in electromagnetics". *International Journal of Electrical Engineering Education*, vol. 40, no. 1 (2003). pp. 79-90.
6. Fawwaz, T.U., Hauck, B.L. "Undergraduate Electromagnetics Laboratory: An Invaluable Part of the Learning Process". *IEEE Conference Proceedings*, vol. 88, no.1 (2000).
7. Dinov, I.D., Sanchez, J. and Christou, N. "Pedagogical Utilization and Assessment of the Statistic Online Computational Resource in Introductory Probability and Statistics". *Journal of Statistics Education*, vol. 16, no. 2 (2008).
8. J. F. Hoburg. "Can computers really help students understand electromagnetics?". *Joint MMM-Intermag Conference Proceedings*, Pittsburgh, PA, 1991.
9. M. de Magistris. "A MATLAB-Based Virtual Laboratory for Teaching Introductory Quasi-Stationary Electromagnetics". *IEEE Transactions on Education*, vol. 48, no. 1 (2005), pp. 81-88.

10. S. Selleri. "A MATLAB Experimental Framework For Electromagnetic Education". *IEEE Antennas and Propagation Magazine*, vol. 45, no. 5 (2003), pp. 86-90.

11. Notaroš, B. M. "MATLAB®-Based Electromagnetics". PEARSON Prentice Hall, 2013.

12. Notaroš, B. M. "Electromagnetics." PEARSON Prentice Hall, 2010.