Filling the Pipeline: Power System and Energy Curricula for Middle and High School Students Through Summer Programs

Chien-fei Chen, Kevin Tomsovic, *Fellow, IEEE*, and Mehmet Aydeniz

***Abstract*—A shortage of U.S. trained power and energy engineers has been predicted in the near future. One approach to solve this problem involves increasing the number of students choosing to study engineering, especially by exposing more students to engineering at an early age, even before high school. This paper presents the curricula and assessment of two summer programs for middle and high school students. We introduced electric and renewable energy concepts, engineering design, and MicroGrid related projects to the students. The survey results indicate that both programs improved students' levels of engineering knowledge, interest in learning and participating in engineering projects, and their intention to choose an engineering career; however, students' confidence in succeeding in engineering or science did not show improvement, which may impact students' willingness to choose engineering as a major. A positive attitude towards engineering among high school students had improved after the program but not among the middle school group. Improving the image of electrical engineering in general, and power systems engineering in particular, remains a challenge.**

***Index Terms*—High school engineering camp, MicroGrid, middle school engineering camp, power and energy systems education, Science, Technology, Engineering and Science (STEM) education.**

I. Introduction

GIVEN the national focus on modernizing the power grid and the trend of an aging engineering workforce, the pipeline of students entering into engineering in the U.S. is not strong enough to support the approaching demand, particularly, in power and energy engineering [1], [2]. In spite of sporadic efforts to increase students' interest in engineering fields, experts suggest that most high school students have a vague picture of engineering and do not feel confident enough in math and science skills [1]. In addition, relatively few parents encourage their children to specifically choose electrical engineering careers. Although a growing effort has been recently paid to elevating the status of engineering education among pre-college students, a systematic power and energy curriculum designed for middle and high school students requires greater attention from educators.

By collaborating with the Diversity Office in the College of Engineering at the University of Tennessee, Knoxville (UTK) and using the Center for Ultra-wide-area Resilient Electrical Energy Transmission Networks' (CURENT) pre-college program as a platform, two summer residential programs for middle school (rising 7th and 8th grade) and high school students (rising 11th and 12th grade) were designed. CURENT is a newly funded Engineering Research Center by the National Science Foundation and Department of Energy. CURENT attempts to inspire pre-college students to pursue engineering majors and careers by focusing on meeting the educational needs of K-12 students and teachers in engineering both in formal and informal settings.

Approximately 32 students were selected to participate within each session with a total participation of 119 students. These two summer residential programs are comprised of sessions of instructions in power and energy engineering and a final project that focuses on the design of a MicroGrid. Specifically, the objectives of these summer programs are: 1) to connect classroom learning to real-life engineering examples, 2) to advance students' engineering knowledge, 3) to inspire students' interest in learning engineering or science, 4) to increase students' confidence in learning and succeeding in STEM fields, 5) to encourage positive attitude towards engineering, and 6) to motivate students' future career intention in choosing an engineering field. The program is a team effort between university administration, CURENT engineering research center education team, faculty, undergraduate and graduate students, and local middle and high school teachers. In this paper, we focus on only the curriculum and design for electrical engineering and energy systems. In addition, we report the effectiveness of these programs.

The rest of this paper is organized as follows: Section II covers the background about the need for power and energy education and daily schedule of our summer programs. The teaching approach and philosophy of the summer programs are discussed in Section III. Specific engineering concepts and designs are introduced in Section IV, and the results of program

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C. Chen is with NSF-DOE Engineering Research Center-CURENT, University of Tennessee, Knoxville, TN 37996 USA (e-mail: cchen26@utk.edu).

K. Tomsovic is with the Department of Electrical Engineering and Computer Science, University of Tennessee, Knoxville, TN 37996 USA (e-mail: tomsovic@utk.edu).

M. Aydeniz is with the Theory and Practice in Teacher Education Department, University of Tennessee, Knoxville, TN 37996 USA (e-mail: maydeniz@utk.edu).

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assessments are presented in Section V. Finally, conclusions are presented in Section VI.

II. Background

In the face of increasing complexity of the problems in the power grid today, there is a greater need for creative and innovative young engineers who are well prepared to meet the challenges of the 21st century. However, the state of engineering education in the U.S. is not promising. National reports show that the number of engineering graduates falls short of industry's demand, particularly in power and energy systems [2], [3]. Student enrollment in electrical engineering in particular has experienced significant decline in recent years despite efforts to increase enrollment in engineering fields. More precisely, electrical engineering experienced a 15% decline between 2001 and 2010 in the total number of undergraduate degrees awarded [4]. According to 2011 statistics, electrical engineering degrees make up about 12% of all undergraduate engineering degrees awarded. More important, only 11.5% of these electrical engineering degrees were awarded to women.

In response to these persistent trends in engineering, both federal government and local educational institutions have placed an increasing emphasis on engineering education in K-12 classrooms. Most school districts across the nation lack the resources to support a robust engineering education program during regular school hours. In addition, an engineering curriculum usually does not conform to testing standards. Therefore, many engineering education activities take place either in the form of an after-school club or a summer program instead of a formal classroom teaching [5]. In fact, studies show that formal pre-engineering programs (e.g., classes) and informal settings (e.g., hobbies) lead to a significant increase in students' self-efficacy to pursue an engineering degree in college [6].

Although it is not a formal education program, our summer programs emphasize standard-based STEM content in a project-based context while integrating engineering concepts at the same time. The fundamental electricity and energy knowledge is taught with an explicit emphasis on core engineering concepts. In addition, engineering design is used to engage students in learning with real-life connections, such as with the micro-grid project, and to reinforce engineering concepts learned in their academic classes.

The overall schedules of these programs are described in this section. Students live within a residence hall on campus for one week, engage in hands-on mathematics and engineering fundamentals activities, compete in engineering challenges through several design projects, participate in counselor-to-peer mentoring, and tour campus engineering buildings. Throughout the program, students team with each other to apply what was learned and work on an engineering design project. The summer programs include the following daily schedules: orientation session, ice breakers and team building exercises (only the first day), classroom learning and activities with mathematics and engineering fundamentals in the morning (9–12), lunch (12–1), classroom learning and activities of electrical engineering and energy system in the afternoon (1:30–3:30), introduction of engineering career and building tours (3:30–5:30), dinner (6) and engineering project design (6–8 pm) and downtime (8–10).

Regarding electrical and engineering learning and design, we introduced micro-grid concepts to the students and asked them to complete a final project representing the micro-grid. This project includes the more general concepts of a power system, storage technologies, such as batteries, and renewable energy. One of the advantages of using the micro-grid project for these students is its connection with a local community as a micro-grid represents a single controlled unit that meets local needs for reliability and supply [7].

III. Teaching Approach

Scholars in education suggest that engineering should not be conflated with other STEM subjects, in particular, science or technology [8]. Therefore, our summer program emphasizes engineering concepts and the design process. The purpose of including engineering design is to introduce to students engineering practices and the thinking and logic processes engineers follow [8]. The approach of teaching students fundamental knowledge in electricity and grid concepts is based on the combination of contextualized and abstract representations in electrical engineering pre-college education [9].

The approach of contextualized representations emphasizes real-life scenarios presenting with life-like images and promotes problem solving. This is done by activating learners' prior knowledge and experiences [9], [10]. For example, solar energy was contextualized by using common houses being made self-sufficient by adding solar panels. In contrast, abstract representations focus on relevant underlying structure and rely more on knowledge conventions for their interpretation by avoiding any real-life context. For example, we delivered a lesson on six different forms of energy including chemical energy, electrical energy, radiant energy, mechanical energy, nuclear energy, and thermal energy. The question of whether contextualized or abstract representation is more effective for learning fundamental engineering knowledge remains to be answered [9]. Still, Reisslein *et al.* [9] found that the combined contextualized-abstract representations are effective in teaching core electrical engineering concepts (e.g., electrical circuit design), helping students to acquire problem-solving skills. In addition, the same study showed that contextualized-abstract representations lowered students' perceived difficulty in learning about electrical circuit analyses.

Our summer programs use the approach of combined contextualized-abstract representations to teach the students about core engineering concepts. Students benefit from the strength of each representation mode. The abstract representations help students focus their attention on relevant problem information rather than superficial information. A realistic or contextualized problem-solving representation is more likely to facilitate student learning because their meanings can be beneficial for long-term memory [11].

IV. Engineering Concepts and Designs

The overall design, activities, and instructions for both middle and high school students are very similar. However, the high school program presents more complex concepts in electrical engineering than the middle school program and uses different materials for designing the final project. The electrical and energy systems portion of the one-week program for middle and high school students generally begins with 20 min of instruction on engineering concepts followed by 30–40 min of various hands-on activities during the day. During a 2-hour time slot in the evening, each group builds a small project daily that is part of the final project. These small projects include building a generator, motor, and wind turbine, solar car, solar house with a solar-powered doorbell, among others. Toward the end of the week, students combine each individual activity and complete the micro-grid design. The final project is presented to peers, faculty, and parents at the conclusion of the program. Below we describe each of the instruction and engineering design sections in detail.

A. Engineering Concepts and Related Activities

The instructional session for middle and high school learners includes the following concepts and related activities (see Fig. 1):

1) what is engineering design?
2) forms of energy followed by demonstration of solar panels, mechanical energy to electric energy conversion in a generator, and chemical energy to electric energy conversion by a fruit battery;
3) electrons, protons, electric force, electric field and static electricity followed by activities with a plasma ball and charged balloons;
4) Faraday's law, motors and generators followed by a hands-on project of using magnets and wire to build a generator to light a bulb and run a simple motor;
5) electric circuits, current, voltage and resistance followed by a worked-out problem showing how to calculate the total resistance of a parallel circuit and a project of open and close circuits;
6) alternating current (AC) and direct current (DC) followed by the AC and DC conversion activity in the lab (high school students only);
7) solar energy followed by the design of a solar house with a solar battery, a solar car and a solar-powered doorbell; and
8) wind energy followed by designing wind turbines to power a light bulb and experimenting with different variable variation.

B. Engineering Design

In order to complete the final project, a micro-grid design, students were required to complete the small pieces of the micro-grid project each day. One key element in our approach is the requirement of hands-on projects for the students using simple materials—not commercial educational kits. As shown in Fig. 1, each group built a simple electromagnetic generator to generate electricity for a light bulb and designed a solar house circuit connected to a solar panel to activate the buzzer for the solar house on the first day. For high school students, they were required to learn AC, DC, and AC/DC conversion in the lab. The generator was hand-wound using cardboard, magnets, and wire. Design decisions included the number of magnets, the number of windings, and so on.

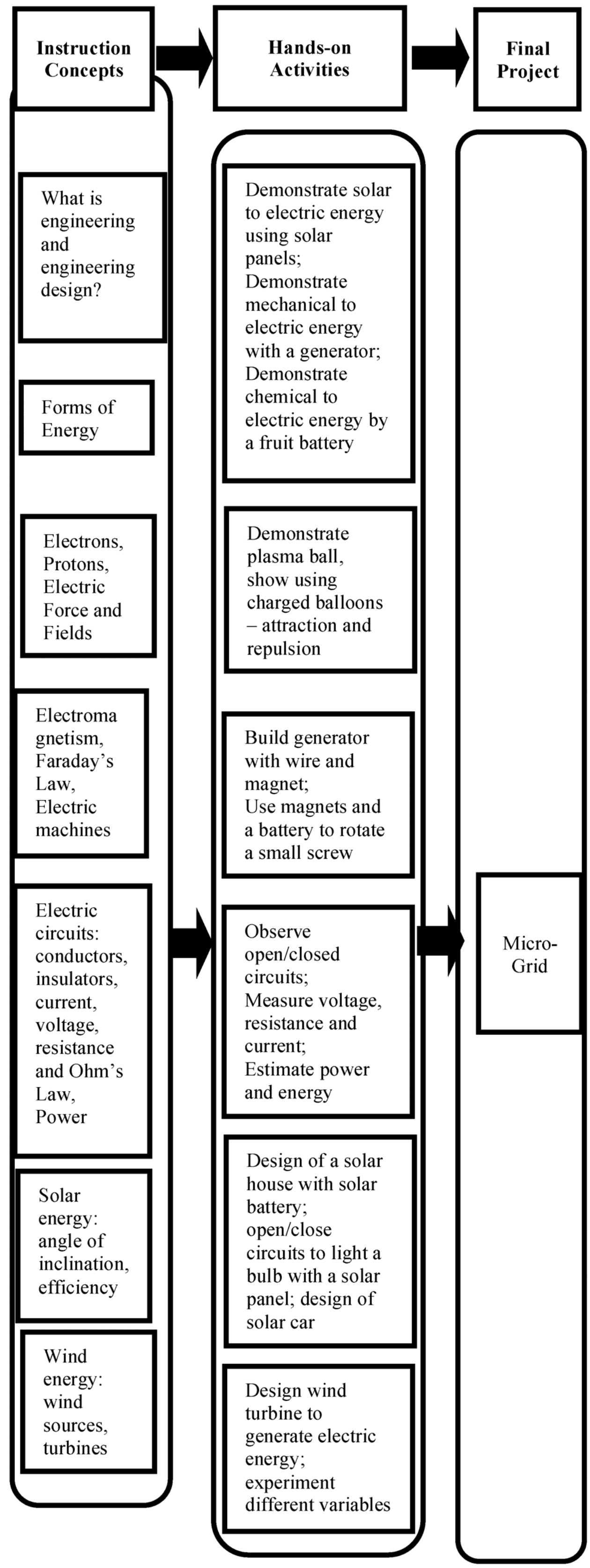

Fig. 1. Instruction concepts and hands on activity.

On the second day, students designed a solar house and installed a solar battery on the roof of the house to represent the concept of energy storage. For the middle school group, students used a recycled cardboard box to cut and design the solar house. The high school group designed solar houses by themselves from simple inexpensive materials that students could cut and shape by hand. In addition, each student built a solar car and competed based on speed and distance travelled. During the program, students had to make decisions on the angle of incline for the solar panel, size and resulting weight of the cars, and other variables.

On the third day, students designed a wind turbine to generate power for a light bulb. The wind turbine project itself was a more involved project than the others. Students had to experiment with different materials (plastic, wood, paper) and by varying the number of blades, pitch of the blades, and shape. Students recorded the measured voltage as they modified the different variables. Participants were asked to relate the concept of converting wind energy to electric energy considering the earlier hand-wound built generators.

All of the small project designs in the evenings were connected with the themes and concepts students had learned during the day. For example, wind turbines and solar projects represent renewable energy concepts and energy conversion problems. On the final day, students completed the micro-grid project by assembling all the small projects together. While it was not possible to truly create an interconnected microgrid, the idea was to conceptualize the microgrid with all of the different components they had designed. In addition, each group presented the engineering concepts learned, in the format of power point (for high school students) or a poster (for middle school) and explained the process of designing the final project to their peers, parents, faculty, and graduate students. During the award ceremony, students were recognized for the best design of generator, solar house, solar cars, wind turbine, final project, and the best presentation. The winners of the best design presented their projects again to university administrators and program organizers.

V. Program Assessment

A. Survey Design

A paper-and-pencil survey was chosen for assessing both middle and high school programs. The surveys were administered before the program (i.e., pre-test) and after the program (i.e., post-test). The survey instructed the students to read a series of questions and rate each question based on a 5-point Likert-type scale ($1 = strongly\ disagree$, $3 = neutral$, and $5 = strongly\ agree$). The survey instrument was designed to measure overall satisfaction, engineering knowledge, interest in taking science classes and participating in science events/projects (for middle school), interest in learning science and engineering (for high school), confidence in succeeding in STEM, attitude towards engineering (for middle school), and future career choice. Because many pre-college students did not have a formal engineering class nor did they have a clear picture of a future career choice, this survey used the term STEM instead of only engineering in some of the survey questions. The questionnaires were similar for both groups except for modifications on evaluation of specific activities, career choice, and learning interest in order to address grade level differences.

The program assessment focuses on the improvement in five areas: engineering knowledge, interest in learning, confidence in learning and succeeding in STEM fields, future career intention, and attitude towards engineering. *Engineering knowledge* was measured by nine questions that assessed students' levels of familiarity with general engineering concepts, electricity, micro-grid, and renewable energy. *Interest* was measured by two questions that assessed middle school students' interest in taking science classes and participating in science-related events or projects. For high school students, this study used four questions to measure their interests in participating in science-related events, hands-on projects, and learning engineering knowledge. *Confidence* was measured by nine and seven questions for middle and high school students, respectively. The questions focused on students' perceived ability in learning and succeeding in STEM fields. Examples of the questions include: "I am confident in learning engineering concepts" and "I am confident in talking about STEM ideas". *Future career* for middle school students was measured by three questions including the future intention to become an engineer, a scientist, or working in a technology field. For high school students, five questions were used to assess their future intention to study a STEM major in college, become an engineer/scientist, or working in a technology field. *Attitude towards engineering* was measured by five statements describing engineering as unappealing or appealing, dull or fascinating, unexciting or exciting, boring or interesting, and means nothing or means a lot.

B. Program Outcomes and Survey Results

The survey response rate for two programs was 97% and 95% for middle and high school participants, respectively. Among the high school participants (28 females and 29 males), the majority of students were African American (45.5%) and white (35.1%) with the remaining participants identifying themselves as Hispanic or Latino (5.3%), Asian (5.3%), and others (8.7%). Their average age was 16.4 years. Among the middle school participants (30 boys and 32 girls), 38.7% of the students identified themselves as White with the remainder of the sample reported themselves as African American (38.7%), Hispanic/Latino (6.5%), Native American (8.1%), and Asian (8.1%). Their average age was 12.4 years.

Overall, the middle school participants were very satisfied (58.1%) or satisfied (32.2%) with the program and no one reported dissatisfaction with the program. Similarly, the majority of high school students were very satisfied (62.5%) or satisfied (35.7%) with the program and no students reported dissatisfaction with the program. Among all the activities, solar car was rated as the most popular one for both the middle and high school students. High school students rated the solar car and basic circuits activity as the most popular. We used a *Paired Samples t-test* to determine if the two means are different between the pre-test and post-test among the same individuals [12].

In terms of outcomes of these programs, middle school students' interests in taking science classes and participating in science projects ($mean = 4.09; S.D. = 0.66; t = 2.65; p = 0.01$) and intention to choose a career in science, engineering, and

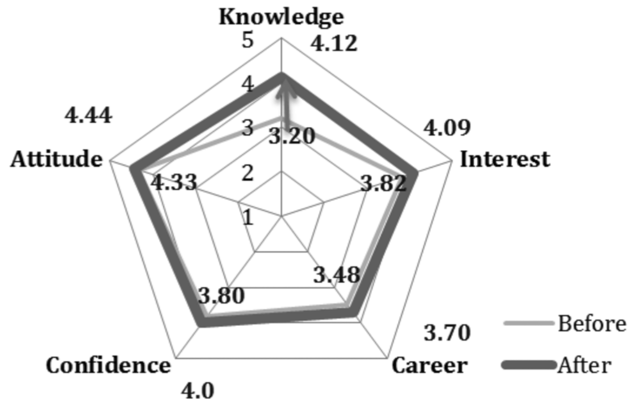

Fig. 2. Results of pre- and post-test measures among middle school students based on a 5-point scale ($N = 62$).

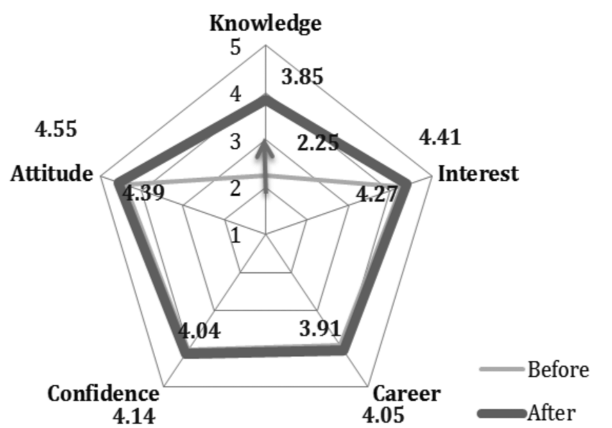

Fig. 3. Results of pre- and post-test measures among high school students based on a 5-point Scale ($\mathrm{N} = 57$).

technology had increased after the program ($mean = 3.70$; $S.D. = 0.58$; $t = 2.89$; $p = 0.005$) (see Fig. 2). Most important, the level of students' engineering knowledge had the most apparent growth ($mean = 4.12$; $S.D. = 0.65$; $t = 10.92$; $p = 0.000$) among all other variables. Yet, students' positive attitude towards engineering did not statistically increase nor did their confidence in succeeding in STEM fields.

Most of the variables measured for the high school students showed a statistically significant increase from pre-test to post-test except for *confidence*. As indicated in Fig. 3, high school students' level of interest in learning engineering and participating in engineering and science projects ($mean = 4.41$; $S.D. = 0.41$; $t = 2.65$; $p = 0.01$) and positive attitude toward engineering ($mean = 4.55$; $S.D. = 0.45$; $t = 2.75$; $p = 0.008$) had increased. Future intention to major in STEM in college and choose a STEM career had slightly increased ($mean = 4.05$; $S.D. = 0.47$; $t = 2.31$; $p = 0.025$). More important, the level of engineering knowledge showed the most obvious increase ($mean = 3.85$; $S.D. = 0.80$; $t = 15.20$; $p = 0.000$) after program completion. Confidence in succeeding in STEM did not reach a statistically significant level of $p < 0.05$, but was closely significant ($p = 0.058$).

Overall, these two summer programs increased students' engineering knowledge, interest in learning engineering and participating in engineering and science projects, and intention to choose engineering as their future careers. Students' confidence in succeeding in STEM fields, however, did not show any improvements. This may be due in part that most of the middle and high school students are either unclear about engineering and technology concepts, nor did they have enough opportunities to learn about engineering at school. In addition, students may lack career awareness about these fields. The positive attitude towards engineering was improved after the program among the high school group; however, it was not significantly improved among the middle school group. Apparently, more attention must be paid to improving students' impression of what electrical engineers do for the middle school students in our programs.

VI. Conclusions

This paper discussed and presented two summer programs in power and energy systems for both middle and high school students. The program appeared to be successful at imparting basic concepts of engineering and increasing students' interest in engineering and their intention to choose an engineering career, but less successful at helping students feel they could succeed in STEM fields.

Based on our quantitative assessment, we believe these programs can be improved by:

- increasing the use of competitions among participants in their designs;
- reducing lecture time in order to increase time spent on the hands-on activities; and
- adding activities designed to increase students' confidence in their ability to succeed in an engineering career, such as adding more emphasis on creativity in the designs.

Despite the general success of summer pre-college programs such as ours, around the country, they are not sufficient to address the shortage of students interested in power engineering. Obviously, we need to adopt a much more comprehensive approach to engineering education than what is currently being practiced. A successful approach must include parent involvement as many parents are also unaware of what engineers do and their encouragement is critical. CURENT targets this approach by holding several family engineering nights at local elementary and middle schools as additional outreach activity. Another successful approach must include the incorporation of engineering concepts into middle and high school core classroom curriculum. In this vein, CURENT has also been working with local teachers to develop power system and energy curriculum that can be directly used to teach existing requirements in math and physics courses.

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Chien-fei Chen received the B.S. degree in English language and literature from National Cheng Kung University, Taiwan, in 1992, and the M.S. degree in communication, and the Ph.D. degree in sociology from Washington State University, Pullman, WA, USA, in 1995 and 2009, respectively.

Her experience includes KSPS-Spokane Public Station, KCTS-Seattle Public Television, Seattle Chinese Television Station, Public Television Service (PTS), Taipei, Vision Communication Public Relation Company, Taipei, Washington State University, and Virginia Tech. Her current research interests include public acceptance of smart grid, renewable energy and energy conservation, and engineering education (K-12 and university). She is a research professor and co-director of education and diversity program at NSF engineering research center, CURENT and an adjunct faculty in the Department of Sociology at the University of Tennessee, Knoxville.

Kevin Tomsovic (F'07) received the B.S. degree in electrical engineering from Michigan Technological University, Houghton, MI, USA, in 1982 and the M.S. and Ph.D. degrees in electrical engineering from the University of Washington, Seattle, WA, USA, in 1984 and 1987, respectively.

He was Department Head of the Electrical Engineering and Computer Science Department at the University of Tennessee, Knoxville (UTK) from 2008–2013. He was on the faculty of Washington State University from 1992–2008. He held the Advanced Technology for Electrical Energy Chair at Kumamoto University, Kumamoto, Japan, from 1999 to 2000 and was an NSF program director in the ECS division from 2004 to 2006. Visiting university positions have included Boston University, Boston, MA, USA; National Cheng Kung University, Tainan, Taiwan; National Sun Yat-Sen University, Kaohsiung, Taiwan; and the Royal Institute of Technology, Stockholm, Sweden. Currently, he is CTI Professor in the Department of Electrical Engineering and Computer Science at UTK and Director of the NSF/DOE ERC CURENT.

Mehmet Aydeniz received the M.S. degree with a concentration in chemistry and the Ph.D. degree in science education from The Florida State University, Tallahassee, FL, USA, in 2001 and 2007, respectively.

He is an Associate Professor of Science Education in the Department of Theory and Practice in Teacher Education, University of Tennessee, Knoxville, TN, USA. He taught high school chemistry for three years in Orlando, FL, USA, and at TIPS program at Duke University for a short time. His research focuses on the nature of science, argumentation, modeling, assessment, and teacher effectiveness. More recently, he has become interested in engineering education research.

Dr. Aydeniz is a member of the National Association for Research in Science Teaching (NARST)'s engineering education strand.