Engaging Middle and High School Students in Learning STEM through Electric Vehicles

Dr. Pam Page Carpenter, NC State University

Pam Page Carpenter, Ed.D. is Director of Education programs for the National Science Foundation Future Renewable Electric Energy Delivery and Management (FREEDM) Systems Center headquartered at NC State University. She has developed and led K-20 programs in renewable energy and alternative transportation with a focus on and science, technology, engineering, and mathematics (STEM). She is an adjunct associate professor in the Technology, Engineering, and Design department at NC State and earned her doctorate in Technology, Engineering, and Design in the College of Education at NC State University.

Dr. Nasim Lari

Mr. Erik Schettig, Wake County Public School System

Erik is a Technology, Engineering, and Design teacher at Middle Creek High School in Apex, NC. He is a Kenan Fellow and has worked extensively with energy related curriculum.

Mr. David Matthew Sander, Wake Forest High School

BS in Technology Education from North Carolina State University with a minor in Science, Technology, & Society 1995 Technology Education Teacher - Wake Forest High School 1995-Present Air Force Outstanding Teacher Award 2003 ITEEA Program Excellence Award 2007 Wake Electric Tarheel Teacher of the Year 2014

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Transportation affects everyone and it is a topic that we can all relate to in our daily lives. The Sustainable Transportation Education Program (STEP) at the Future Renewable Electric Energy and Delivery Management (FREEDM) Systems Center at North Carolina State University is in the eighth year of an electric vehicle program for middle and high school students. The STEP program's purpose is to prepare middle and high school students to become informed and engaged in learning about the electrification of transportation, battery technologies and storage, and standards aligned with science, technology, engineering, and math (STEM). The STEP program provides teacher training and curricula on Plug-in Electric Vehicles (PEVs), Smart Grid, and careers in science, engineering, and technology as it relates to the automotive and the supporting infrastructure. The program has had an impact on over 1,500 students and teachers in the respective state since its inception. STEP's curriculum is a STEM based program that includes problem-solving, critical thinking and inquiry-based learning with relevance to real world issues. STEP includes a hands-on component, which includes a 1/10 scale model PEV as students learn about battery technologies, powertrain, chassis design and other related topics.

The STEP competition gives students a relevant learning experience through an applied approach (theory-to-practice) with sustainable transportation. The program parallels the engineering challenge of designing plug-in electric vehicles on a 1/10 scale. Students are challenged to design efficient battery powered vehicles and solar charging station to recharge the vehicle's batteries.

Introduction

Existing literature emphasizes the importance of hands-on learning. Nersessian believes hands-on experiences constitute the core of science learning (Ma and Nickerson, 2006). Most recently, Bigler and Hanegan (2011) have found that allowing students to use equipment for DNA extraction and gel electrophoresis in a biotechnology class improved students' content knowledge. The use of laboratories in enhancing courses is not only important in the sciences, but also in engineering. Engineering professors use labs as a place to apply concepts and connect classroom studies to future employment (Ma and Nickerson, 2006). The U.S. struggles with a skilled STEM workforce and particularly as the workforce retires. It is imperative that the U.S. continues to engage students in both formal and informal learning environments to develop an interest, awareness, knowledge, and skills in STEM.

Science and Engineering Indicators (2016) reported that while U.S. graduation continues to rise and there is an increase in science and math literacy scores overall, the U.S. scores in math and science literacy scores are below the average scores compared to other developed countries. The report also indicates that students take less computer science and engineering courses in high school with more males enrolling in these courses than females.

There are multiple reasons that STEM career pathways may be lacking in K-12 education in the United States and contributing to a shortage of workforce in STEM. Most significant is that students need a strong foundation in science and math in order to prepare to train for STEM professions. Science and technology courses are few and students may not have access to take courses in STEM areas contingent on the availability of teachers and courses (US Congress Joint Economic Committee, 2012). It is important to provide the K-12 community with ample opportunities in STEM and to be able to apply STEM in real world environments making it relevant and meaningful.

STEP aims to increase students' awareness and knowledge of sustainable transportation through a STEM-based curriculum and engage them in a theory to practice competitive event that engages students in the engineering design process. Middle school student are challenged to design, build and test a 1/10 scale model electric vehicle and solar charging station to charge the vehicle's batteries. High school students modify and test a RC car to improve efficiency and design build and test a solar charging station for their vehicles. The curriculum introduces students to Newtonian physics (net force, acceleration, velocity, etc.) and electronics (circuits, voltage, amperage, battery charging/discharging, etc.). Through virtual and physical modeling students apply this knowledge to solve the engineering design challenge; designing a vehicle for maximum range and speed and the most efficient charging station.

STEP is dedicated to educating middle and high school students on sustainable transportation and its associated STEM careers in engineering while giving students a look into the future of transportation and our transportation infrastructure. The program encourages problem-solving, critical thinking and inquiry-based learning in the context of real world issues. Through the program, students design and build their own electric vehicles and charging stations.

The Engineering Design Challenge

Engineers are faced with a challenge of designing a sustainable transportation infrastructure that is less dependent on fossil fuels. Tesla, Nissan, Ford, General Motors, and other automotive manufacturers have demonstrated commercial success with hybrid and electric vehicles. Multiple metropolitan areas have hybrid bus systems in place. The engineering design challenge is to design a vehicle that maintains an acceptable level of performance while having the longest range. This is the real-life challenge that engineers are facing and trying to solve by improving drivetrain efficiency and battery storage capacity. Another challenge involves improving the charging system to decrease the charging time. The program provides students an opportunity in designing a plug-in electric vehicle and charging station.

High School Design Challenge

With vehicle fuel types, transitioning to alternatives and the establishing a supporting infrastructure it is important to provide a hands-on experience with tools and models of technology that students will see in the future. The high school portion of program provides such an experience through the application of a radio controlled electric car acting as the model of a full-size electric vehicle and the building of a solar charging station. Students are tasked with building, testing, and documenting their model electric vehicle. The model electric vehicles include the same basic components as a full size electric vehicle such as a battery system, controller, and electric motor. Students are able to change gear ratios to explore the variety of gearing, manipulate suspension, explore 3D printing parts, and determining which combination of components results in the top performing, most efficient vehicle. In addition to working with the model vehicle, students are to build a solar charging station. Using a system of photovoltaic panels, student build a system that will appropriately angle the panel towards the sun to power a battery charger which charges the battery they use in their RC Vehicle. Teams have the options of including a larger number of panels, more powerful panels or more efficient panels, as well as solar tracking technology. The students are encouraged to work with their community for sponsorships and gathering resources of information. Throughout their design and engineering process, the students must document their resources and design process. This includes collecting and analyzing data from testing their vehicle, maintaining a budget that cannot be exceed the designated amount, as well as a clear list of resources they utilized. Once a year, teams come together for the annual competition at North Carolina State University with their portfolios and equipment to present their designs as well as compete with other schools in order to test the speed of their vehicle and the efficiency of the solar charging station.

Open Source Curriculum

The STEP project team has developed STEM-based middle school and high school curricula. The curricula are publicly available through the project website step.gridc.net. Students learn about the history and environmental impacts of electric vehicles. The curricula also include overviews of the following:

- Petroleum and Transportation Trends
- Various Safety Aspects (Tool, Vehicle, Electricity, Battery)
- Electric Vehicle Types, Electricity (Current, Power, Voltage, Resistance)
- Photovoltaic Panels
- Solar Irradiance
- Wind Energy, Wind Power, and Wind Turbines
- Battery (Types, Charging, Charging Tips)
- Electric Motors (AC Motor, DC Motor)
- Drivetrain (Gear Ratio, Controls, Structural, Chassis, Suspension, Body Design, Drag)
- Modeling (Virtual, Engineering Design Process)
- Charging Electric Vehicles (Electric Vehicle Supply Equipment Types, Charging Locations, Energy Consumption)
- The Smart Grid, and
- Career Opportunities.

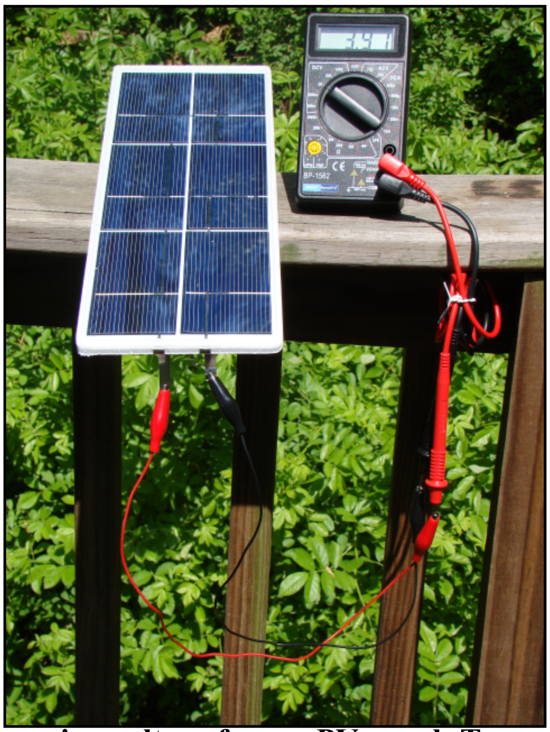
Each topic is accompanied by activities to enhance students' understanding. Figure 1 presents a screenshot of a sample activity for middle school students. The high school curriculum follows a similar, yet more detailed and advanced format. Figure 2 shows a screenshot of a sample activity for high school students. The standards addressed within the curriculum are listed in Table 1.

Sample Middle School Activity

Activity 4: Graphing Solar Energy

A) At different times during the day, a photovoltaic (PV) panel produces varying amounts of power from the sun. What variables do you think affect the power output of a PV panel?

B.) Research possible factors that play a role in how much power a PV panel produces. Take note of certain angles and directions of exposure in varying areas of the world. To best measure the energy output of your PV panel, create a circuit using the panel and the multimeter. However, instead of using a battery pack, use your PV panel as the source of energy. Be aware that if you get a negative reading on your multimeter, then simply switch the connection points. It may also help to label the positive point of the panel.



Set you multimeter by placing the probes in VΩmA and set the dial to DCV 20

Measuring voltage from a PV panel: To measure voltage above 20V set dial to 200 DCV, connect the multimeter to the PV panel as in the photo above.

C) Power produced by the PV panel depends on how much sunlight is hitting the surface. On cloudy days, one will notice that a panel produces less energy because less sunlight is making its way to the surface. Take your PV panel and attach it to a multimeter to measure the voltage that is produced. Do things such as holding the panel at different angels or covering up certain parts of the panel and note their results on the voltage produced.

Affect on Panel:	**Voltage:**
Held at angle 0◦	
Held at angle 45◦	
Held at angle 90◦	
Held at angle 135◦	
Cover up a third of the panel held at 45◦	
Cover up half of the panel held at 45◦	

D) Construct a chart of energy output versus angle of panel to present to individuals a visual for how angles play a role in determining power output. For examples of solar charts, visit insert hyperlink.

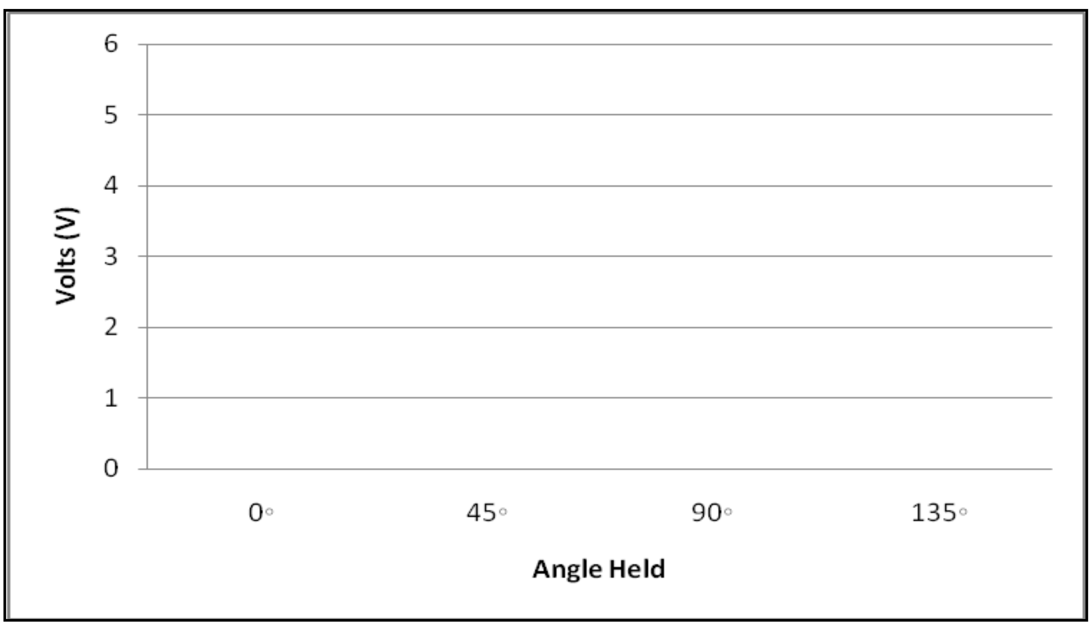


Figure 1 Middle School Activity

Sample High School Activity

Activity 7: Gear Ratios

A. Different gear ratios add more control to how the vehicle operates. Can you think of situations where you would have to have more speed than power and vices versa?

B. A set of gears came with your R/C vehicle. These gears are valuable because of the differences they can have in how your vehicle performs. Find out as much as you can about the gears. Note the different number of teeth and the varying sizes. Read any warnings and directions regarding the gears of the vehicle. These can be found with the gears or in the instructions of the vehicle. Also find out how to replace gears on your motor. The instruction that came with the vehicle will be able to supply this information (page 15).

C. Choose four gears from the packet you received and set up a test area for your vehicle. Hold an initial test with the gear that the vehicle comes with. In your test area drive your vehicle at a constant speed (not high). Record about how long it takes to complete a lap. If your radio control does so, set your vehicle at a constant speed (the same speed for each test). On the provided radio control it should be the left knob that when rotated allows for a constant speed to be achieved. If this cannot be done, then try and use the same pressure applied to the trigger for each test. Change the pinion gear for each test and conduct the same procedures. Record how long it takes to complete the test lap as well as the ratio used for each test.

D. Fill in the table for the tests you run with the differing gear ratios. Feel free to create your own table that may have additional information you deem necessary.

Gear Ratio:	Track Length:	Time:

Figure 2 High School Activity

Table 1.

International Technology Engineering and Education Association's (ITEEA) National Standards Addressed

Technology Standards (ITEEA, 2000/2002/2007)	
Standard 1	Students will develop an understanding of the characteristics and scope of technology (Objectives F, G, H, I, L, M)
Standard 2	Students will develop an understanding of the core concepts of technology (Objectives M, N, P, Q, T, W, X, CC, BB)
Standard 3	Students will develop an understanding of the relationship among technologies and the connections between technology and other fields of study (D, F, G, H, J)
Standard 4	Students will develop an understanding of the cultural, social, economic, and political effects of technology (D, E, H, I, K)
Standard 5	Students will develop an understanding of the effects of technology on the environment (D, F, G, H, I)
Standard 6	Students will develop an understanding of the role of society in the development and use of technology (D, E, F, G, J)
Standard 7	Students will develop an understanding of the influence of technology on history (C, D, G, H, I)

Table 1 (Cont'd)

National Standards Addressed

Standard 8	Students will develop an understanding of the attributes of design (E, F, G, H, J, K)
Standard 9	Students will develop an understanding of engineering design (F, G, H, I, J, K, L)
Standard 10	Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving (F, H, I, J, L)
Standard 11	Students will develop the abilities to apply the design process (H, J, K, L, M, N, O, P, Q, R)
Standard 12	Students will develop the abilities to use and maintain technological products and systems (H, I, J, K, L, M, N, O)
Standard 13	Students will develop the abilities to assess the impact of products and systems (F, G, H, I, J, K, L)
Standard 16	Students will develop an understanding of and be able to select and use energy and power technologies (E, F, G, H, I, J, K, L, M, N)
Standard 17	Students will develop an understanding of and be able to select and use information and communication technologies (H, I, K, M, N, O, P)
Standard 18	Students will develop an understanding of and be able to select and use transportation technologies (F, G, H, L, M)
Science Standards (AAAS, 1993/2009)	
6th Grade	*Competency Goal 1:* The learner will design and conduct investigations to demonstrate an understanding of scientific inquiry (Objectives: 1.01,1.02, 1.03,1.04, 1.05,1.06 ,1.07,1.08, 1.09); *Competency Goal 2:* The learner will

	demonstrate an understanding of technological design (Objectives: 2.01, 2.02, 2.03, 2.04); *Competency Goal 6:* The learner will conduct investigations and examine models and devices to build an understanding of the characteristics of energy transfer and/or transformation (Objectives: 6.01, 6.02, 6.06, 6.07); *Competency Goal 7:* The learner will conduct investigations and use technologies and information systems to build an understanding of population dynamics.
7th Grade	*Competency Goal 1:* The learner will design and conduct investigations to demonstrate an understanding of scientific inquiry (Objectives: 1.01, 1.02, 1.03, 1.04, 1.05, 1.06, 1.07, 1.08, 1.09); *Competency Goal 2:* The learner will demonstrate an understanding of technological design (Objectives: 2.01, 2.02, 2.03, 2.04); *Competency Goal 3:* The learner will conduct investigations and utilize appropriate technologies and information systems to build an understanding of the atmosphere (Objectives: 3.01, 3.02, 3.03, 3.04, 3.05); *Competency Goal 6:* The learner will conduct investigations, use models, simulations, and appropriate technologies and information systems to build an understanding of motion and forces (Objectives: 6.01, 6.02, 6.03, 6.04, 6.05, 6.06).
8th Grade	*Competency Goal 1*: The learner will design and conduct investigations to demonstrate an understanding of scientific inquiry (Objectives: 1.01,1.02, 1.03, 1.04, 1.05, 1.06, 1.08, 1.09); *Competency Goal 2*: The learner will demonstrate an understanding of technological design (Objectives: 2.01, 2.02, 2.03, 2.04).

Table 1 (Cont'd)

National Standards Addressed

Mathematics Standards (NCTM, 2000)	
6th Grade	*Competency Goal 3*: The learner will select and use appropriate tools to measure two- and three-dimensional figures (Objectives 2.01, 2.02); *Competency Goal 4*: The learner will understand and determine probabilities (Objective 4.06)
7th Grade	*Competency Goal 1*: The learner will understand and compute with rational numbers (Objectives 1.01, 1.03); *Competency Goal 2*: The learner will understand and use measurement involving two- and three-dimensional figures (Objective 2.1); *Competency Goal 4*: The learner will understand and use graphs and data analysis (Objectives 4.01, 4.02, 4.03, 4.04, 4.05, 4.06); *Competency Goal 5*: The learner will demonstrate an understanding of linear relations and fundamental algebraic concepts (Objective 5.01)
8th Grade	*Competency Goal 1*: The learner will understand and compute with real numbers (Objective 1.02); *Competency Goal 4*: The learner will understand and use graphs and data analysis (Objectives 4.01, 4.02, 4.03)

Annual Competition

STEP hosts annual competitions for middle and high schools that allows students to apply their knowledge and skills in a competitive community. The competitions are held on the North Carolina State University and expose the middle and high school students to a university campus, undergraduate and graduate students, and opportunities to learn about college life. Volunteers for the program include undergraduate and graduate research students studying electrical and computer engineering, staff, and industry. STEP has multiple schools in rural areas of the state so this is another important aspect of the program to expose the students to a university environment. Detailed rules and regulations for the middle school and high school competitions are provided on the project website. The teams were selected through a selective application process. Teachers were made aware of the program through project presentations at various conferences and individual schools. The project has expanded to Maryland and plans to involve more states in the future.

Figure 3 Undergraduate Research Scholars Volunteer at the Competition 2016

Middle School Competition

The purpose of the middle school competition is to allow students to work as part of a team to demonstrate their knowledge of alternative transportation systems by testing, modifying, and demonstrating a functional model electric car and solar charging station. For the competition, participants design and fabricate a battery powered vehicle and solar charging station.

Evaluation of their final products is based on a technical report, quality of construction, teamwork, and the performance of the vehicle and charging system. To demonstrate their understanding of the design process, each team is asked to prepare a technical report. The students should document the results of testing different models (gear ratios, batteries, etc.) and information about research in the solar charging station design process that brought them to their ultimate design. Winners are announced in the categories of Design and Construction, which involves an evaluation of the appearance of and quality of work on the vehicle and charging station; Technical Report; Innovative Design and Creativity, which pertains to the vehicle body and chassis design, power and drive train design; Speed and Endurance Races. The Design and Construction, Technical Report, and Innovative Design and Creativity categories are judged by three independent judges to assure impartiality and fairness. Figure 3 shows students participating in the middle school event.

Figure 3.

Figure 4 Middle School Students

High School Competition

The STEP high school competition is designed to encourage students to work as part of a team to demonstrate knowledge of alternative-fueled transportation systems by testing, modifying, and demonstrating a functional radio-controlled electric car in conjunction with an innovative solar charging station that is used to recharge the battery pack for the endurance events. Students modify, test, demonstrate, and fabricate a radio controlled car and solar charging system that can successfully navigate various courses during a timed demonstration.

Figure 5 High School Students Exhibit

The evaluation of each team's work is based on a technical report, quality construction, teamwork, and the performance of the vehicle and charging system. The technical report should document various tests of different models (gear ratios, batteries, motors, etc.) and provide information on the solar charging station design process, focusing on trade-offs of various existing designs.

A lap counter system and timer is used to monitor the car's times more closely. This technology gathers data on the student-made vehicle that helps determine the winner and provide feedback to the teams, which can be used to improve their performance in future competitions. Through the use of such technology the team is able to lead by example and show students how technology can be engineered to help in certain tasks (such as lap counting and timing).

Winners are announced in the categories of Design and Construction, which addresses the appearance, quality of work, functionality, and the innovation of design of the solar charging stations; Technical Report; Races. The Design and Construction, Technical Report, and Vehicle Paint Scheme categories are judged by three independent judges to assure impartiality and fairness.

Figure 6 Judging at Past Competitions

Figure 7 High School Troubleshooting

Career Awareness & Motivation Survey

In an effort to assess students' level of awareness of and motivation for exploring renewable energies, the program team distributed a Career Awareness & Motivation Survey (CAMS) to students attending the annual competition (Appendix A). A total of 25 students responded to the survey, with 44% female and 56% of respondents male.

Table 2

Item	Mean	Standard Deviation
I have heard the term alternative transportation	4.32	0.90
I have had one [or more] teacher talk about alternative transportation	4.20	0.96
I have participated in a classroom activity involving alternative transportation	3.80	1.32
I can name a form of alternative transportation	4.04	1.02
I can describe one way alternative transportation directly impacts my life	3.80	1.19
I can name a college major that studies alternative transportation	2.76	1.13
I can name a company that works in the area of alternative transportation	2.88	1.27

I can describe one way alternative transportation may benefit society/humankind	4.04	1.02
Read news stories or magazine articles about alternative transportation	3.56	1.23
Watch a program about alternative transportation	3.60	1.12
Learn about college majors in which I can learn more about alternative transportation	2.92	1.04
Work in fields that deal with alternative transportation	3.40	1.19
Investigate how alternative transportation impacts society	3.48	1.19
Casually talk about alternative transportation	3.28	1.14
Learn about companies that work in the area of alternative transportation	3.24	1.20

* Data from 2012 STEP event.

The results suggest that what while the majority of students have had exposure to the topic of alternative transportation in the classroom; the students are not aware of college majors that investigate alternative transportation or career pathways that would place them in this field. It may be beneficial for teachers to better present such majors and career pathways in the classroom.

Program Training

Each year STEP holds a teachers' workshop in September at the FREEDM Center. Training videos were created to ensure that teachers had access to the hands-on application after they completed the workshop. There is an annual competition with a range, speed, design, and plug-in with a focus on battery technologies and charging from the students' designed solar charging stations. Part of the program and competition includes developing students' soft skills (communications both oral and written), decision-making, leadership, and teamwork.

Figure 8 Teacher Training

The project team has developed various training videos, which are publicly available through the project website. The training videos include an overview of the curriculum, rules, equipment, and supplies for the middle school and high school competitions. Additionally, teachers scheduled to participate in the competition are encouraged to attend a workshop that provides an overview of the project and competition. Teachers build their own model cars during the workshop and receive further guidance and instruction on building their vehicles.

Conclusion

In 2008 co founders and administrators were returning from a trip to Washington, D.C. after presenting another renewable energy project Green Research funded by the

National Science Foundation) and a presentation on Capitol Hill. Both had been involved in other electric vehicle programs, but wanted to provide opportunities that were affordable and accessible for STEM teachers to learn about alternative vehicles and the infrastructure. Another consideration was having girls at the middle and high school levels actively involved in the program and from this conversation the program was started. Funding was provided initially by the National Science Foundation, a local utility, and the Navy. The pilot program was started in 2009 with five schools. The challenges have included funding and the program has been moved to multiple colleges and centers. STEP is now part of the pre college program at the FREEDM Center at North Carolina State University and is funded by generous support from Duke Energy.

In 2017, the program plans to pilot a program to increase young women's participation at the high school level. As addressed earlier in the paper, there are few high school girls taking courses in engineering and computer science in high school and entering the workforce in the automotive industry. The purpose of this new pilot is to provide a platform for young women to be engaged in STEM activities. Veteran schools that return are allowed to register a second team to participate provided that their second team is an all girl team. Teams are also encouraged to provide additional outreach opportunities for their female team members.

The program immerses students in learning about the electrification of transportation and its associated careers. The program also provides teacher training and curricula on electric vehicles, plug-in hybrid electric vehicles (PHEVs), Smart Grid, alternative fuels, and careers in science, engineering, and technology, while providing application to the automotive and supporting infrastructure. This program has impacted many people and plans to further expand regionally and nationally; thereby broadening opportunities and enabling the participation of a greater population of students.

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Appendix

Please check one box: I am ð Female ð Male

Please rate how strongly you agree or disagree with each of the following statements.						
#	**Item**	**Strongly Agree 5**	**Agree 4**	**Neither Agree Nor Disagree 3**	**Disagree 2**	**Strongly Disagree 1**
Awareness / How much do you know about alternative transportation?						
1	**I have heard the term alternative transportation.**	**5**	**4**	**3**	**2**	**1**
2	**I have had one [or more] teacher talk about alternative transportation.**	**5**	**4**	**3**	**2**	**1**
3	**I have participated in a classroom activity involving alternative transportation.**	**5**	**4**	**3**	**2**	**1**
4	**I can name a form of alternative transportation.**	**5**	**4**	**3**	**2**	**1**
5	**I can describe one way alternative transportation directly impacts my life.**	**5**	**4**	**3**	**2**	**1**
6	**I can name a college major that studies alternative transportation.**	**5**	**4**	**3**	**2**	**1**
7	**I can name a company that works in the area of alternative transportation.**	**5**	**4**	**3**	**2**	**1**
8	**I can describe one way alternative transportation may benefit society/humankind.**	**5**	**4**	**3**	**2**	**1**
Motivation / What is your motivation/interest in alternative transportation? I plan to:						
9	**Read news stories or magazine articles about alternative transportation.**	**5**	**4**	**3**	**2**	**1**
10	**Watch a program about alternative transportation.**	**5**	**4**	**3**	**2**	**1**

11	**Learn about college majors in which I can learn more about alternative transportation.**	**5**	**4**	**3**	**2**	**1**
12	**Work in fields that deal with alternative transportation.**	**5**	**4**	**3**	**2**	**1**
13	**Investigate how alternative transportation impacts society.**	**5**	**4**	**3**	**2**	**1**
14	**Casually talk about alternative transportation.**	**5**	**4**	**3**	**2**	**1**
15	**Learn about companies that work in the area of alternative transportation.**	**5**	**4**	**3**	**2**	**1**
16	**Work for a company in the area of alternative transportation.**	**5**	**4**	**3**	**2**	**1**

COMMENTS: