Educating STEM Teachers on Thermoelectrics – a Promising, Emerging Technology

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Abstract

A two-day hands-on workshop at the University of Memphis familiarized 12 local STEM teachers in elementary, middle and high school on thermoelectrics with the goal of familiarizing our future energy leaders on one of the less well-known, emerging alternative/renewable energy technologies. Thermoelectrics uses heat to generate electricity and electricity to transfer heat and is one of the unfamiliar alternative/renewable energy technologies. It has the potential to significantly reduce our dependence on fossil fuels. In order for future energy leaders to most effectively solve tomorrow's greatest energy challenges, they should be cognizant of all technologies. Several heat and energy-relevant standards from the new Tennessee science standards were demonstrated – including renewable/alternative energy standards. Also, teachers were taught basic electrical theory and measurements which were practiced with hands-on demonstrations. Convincing survey results is evidence that the workshop was highly successful. Workshop outcomes, lessons learned and survey results will be discussed.

Keywords

Alternative Energy, Heat, Renewable Energy, STEM, Thermoelectrics

Introduction

Future energy leaders should be cognizant of all alternative energy technologies to most effectively and efficiently solve tomorrow's greatest energy challenges. Hence, there is a need to expose and educate students on emerging, promising, less well-known technologies such as thermoelectrics (TEs). TEs uses heat to generate electricity and electricity to transfer heat and is one of the unfamiliar alternative/renewable energy technologies. TE devices provide a clean and environmentally friendly technique for converting energy from one form to another form[1-2]. It has the potential to significantly reduce our dependence on fossil fuels and can drive technology innovation because TEs will help engineers visualize new solutions to the world's energy problems. Even though there are other interesting and unfamiliar alternative energy technologies (e.g., biomass, tidal, etc.), TEs was the technology of choice for this work because Professor Fields is currently performing research on TE materials and devices, and TE devices are easy to obtain and are inexpensive; hence, TE concepts and applications can be demonstrated at a reasonable price and without too much difficulty.

A two-day hands-on workshop at the University of Memphis educated 12 local STEM teachers in elementary, middle and high school on TEs where the overarching goal was for the teachers to take the activities and lessons learned back to their schools and familiarize their students with

TEs. Teachers were taught the basic theory behind TEs and were inspired to adopt TEs as an alternative energy source. Several heat and energy-relevant standards from the new Tennessee science standards were demonstrated – including renewable/alternative energy standards. In addition, teachers were taught basic electrical theory and measurements which they practiced with hands-on lab demonstrations.

The workshop was sponsored by Constellation ® – an Exelon Company, and aligns well with Constellation's three Energy to Educate Innovation Themes: 1) Energy in Transportation, 2) Backyard Generation and 3) Zero Waste. After the teachers familiarize their students with TEs, the students will be in a position to innovate ways to use TEs at home, school, etc. to generate electricity from waste heat.

Discussion

Photovoltaics and wind turbines are two of the most well-known renewable and alternative energy sources discussed in grades three through twelve. While these are amongst the most mature and efficient (in terms of energy-conversion) renewable energy technologies, STEM educators and students need to be aware of other promising, emerging, less well-known alternative/renewable energy sources such as TEs.

TE generators (TEGs) use heat to generate electricity and TE coolers (based on the Peltier effect) use electricity to transfer heat. There are endless applications for TEGs and TE coolers (TECs). Wherever there is waste heat (e.g., automobile exhaust), TEGs can be used to convert some of the waste heat into electricity. On the other hand, one can imagine many applications for TECs (e.g., cooling your car seat, cooling electronic parts, replacing the air conditioner in your car, etc.).

Figure 1 shows a how a TEG and TEC works. The left figure is a TEG application and shows a heat source causing negative and positive charges to flow towards the cooler side. The electrical charges flow through the resistor (the scrigley line symbol). The right figure is a TEC application where the voltage source at the very bottom of the figure forces electrical charge to flow through the N and P TE materials, and in the process, heat is transferred from the object being cooled (the cooled surface) to the heated surface (dissipated heat block).

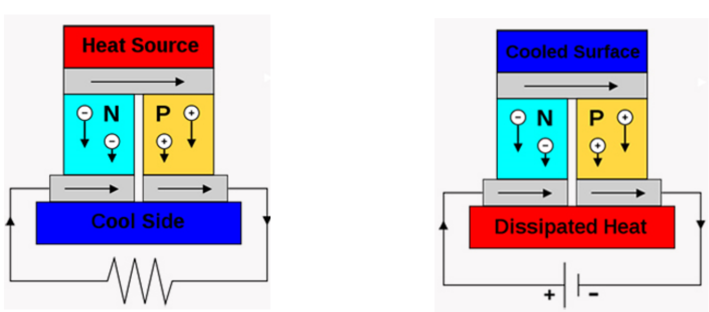

Figure 1. Thermoelectric Generator and Thermoelectric Cooler [3].

TEGs and TECs look similar. A TEG can also be used as a TEC and vice versa: the only difference is that the TEG has been optimized for generating electricity whereas the TEC has been optimized to use electricity to transfer as much thermal energy as possible.

The flow of the workshop is described next. Teachers were first introduced to the fundamental electrical concepts of current, voltage, resistance and electrical power. This was followed by a lab activity where they had a chance to measure voltage and resistance using the handheld digital multimeter in their kit. Subsequently, the teachers were introduced to Ohm's law, and they got a chance to use it to compute current. Then, the teachers were introduced to TEs (including the Seebeck effect and the Peltier effect). The last concept presented was the heat-electricity analogy in table 1.

Table 1. Heat-electricity analogy.

Electrical	Heat
$\Delta V = IR$	$\Delta T = QR_{th}$
I	Q
R	R_{th}

ΔV corresponds to ΔT. The potential difference, ΔV, is the electrical driving force that forces electrical current to flow in a circuit. A temperature difference, ΔT, is the thermal driving force that forces heat (i.e., thermal energy flow or thermal current) through a material. I is electrical current and corresponds to Q which is thermal current (i.e., heat). Electrical current flows in an electrical circuit. Thermal current flows through air, objects and materials. R is electrical resistance and corresponds to R_{th} (thermal resistance). Electrical resistance impedes the flow of electrical charge. Thermal resistance impedes heat. Notice the word choice in the last sentence – "impedes heat". "Heat" is the flow of thermal energy; hence, the ubiquitous phrase "heat flow" is incorrect because heat already implies "flow".

The heat-electricity analogy was introduced because it allows one to better understand heat when one understands the electrical fundamentals mentioned above. In addition, it allows one to better understand many everyday occurrences related to heat.

The remainder of the workshop focused on many of the heat and energy-relevant standards from the new Tennessee science standards[4] and on relating TEs to as many of the standards as possible through lab exercises. Several of the following standards in the workshop manual were covered: 3.PS3.2, 4.PS3.3, 4.ESS3.1, 6.PS3.1, 6.PS3.4, 6.ESS3.1, 6.ESS3.2, 6.ETS1.2, CHEM1.PS3.1, CHEM1.PS3.4, PHYS.PS3.2, PHYS.PS3.5, PHYS.PS3.6, PHYS.PS3.7, PHYS.PS3.14 and PHYS.PS3.15.

Each of the 12 teachers in attendance was given a kit containing miscellaneous parts and instruments – including a TE generator and a TE cooler – to take back to their schools to demonstrate TEs so that students can witness how TEs is applied in the real world via 1) demonstrations and lab exercises that convert waste heat to electricity and 2) demonstrations that use electricity to transfer heat. Figure 2 shows the parts in the kit, and table 2 is the corresponding parts list.

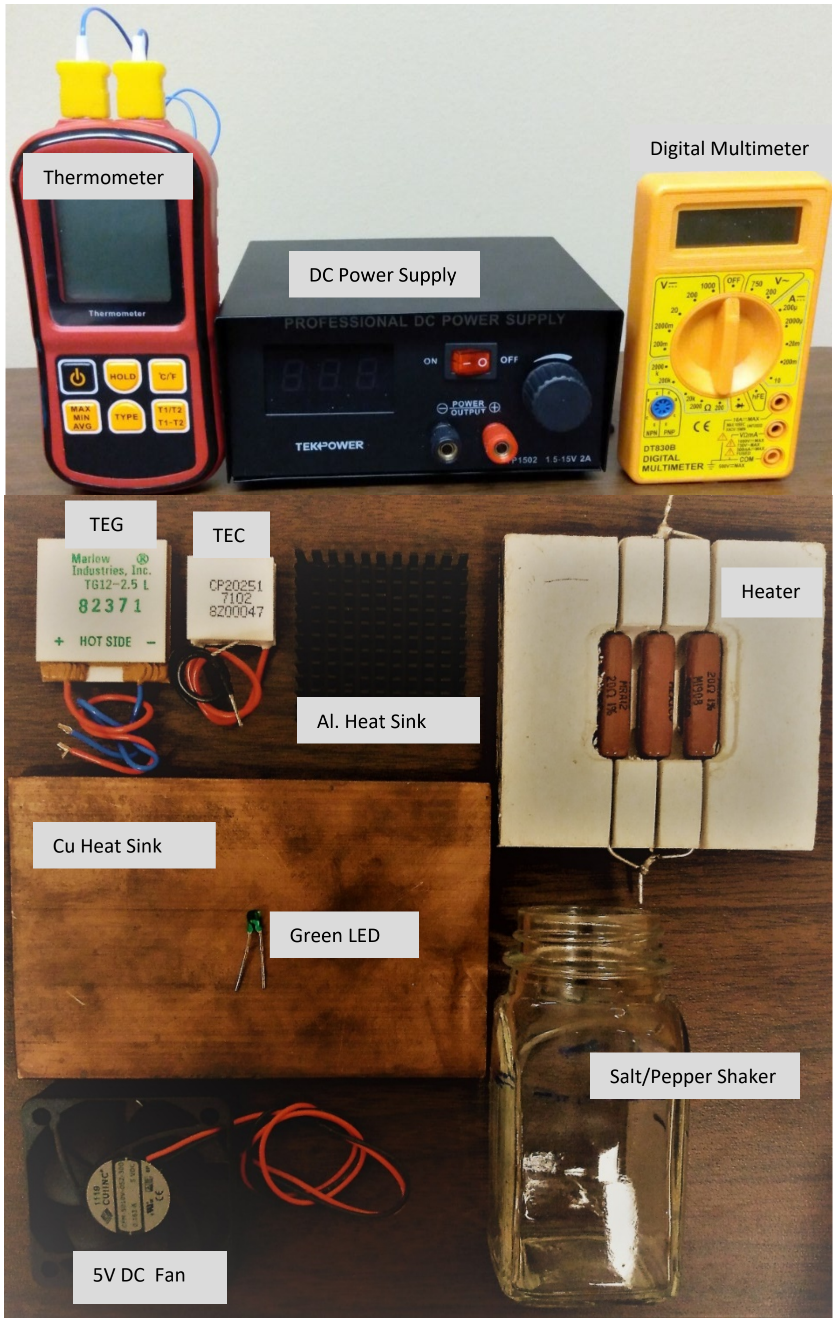

Figure 2. Kit parts.

Table 2. Kit part numbers.

Part Description	Part Number or Supplier
Tekpower DC Power Supply	TP1502
Digital Multimeter	DT830B
Kamtop 2-Channel Digital Thermometer	GM1312
Marlow Industries, Inc. TEG	TG12-2.5-01LS
CUI Devices TEC	CP20251
Heater (Three 10 watt, 20 ohm resistors embedded in a calcium silicate insulator block)	Made in-house
CUI Inc. Axial 5VDC Fan	CFM-5010V-052-300
Copper Heat Sink (70mm x 70mm x 6mm)	Cut from copper sheet from McMaster-Carr
Black Aluminum Fin Heat Sink (40mm x 40 mm x 11mm)	Purchased from Amazon
Green Light Emitting Diode	From Digi-Key LED Kit
Alligator Test Leads	Purchased from Digi-Key
Salt & Pepper Shaker	Purchased from Family Dollar

Unfortunately, only six of the 16 standards were covered due to the fact that the workshop was only two days. However, each teacher was given a workshop manual that contained all of the necessary background information as well as the activities and lab procedures. Even though only six of the 16 standards were covered, the teachers got a chance to observe how TECs and TEGs work.

Two of the teachers were from elementary schools, two were from middle schools, and the other eight were high school teachers. Again, familiarizing STEM teachers with an emerging, promising, less well-known technology so that they can broaden the renewable/alternative energy technologies that students are aware of was the main focus of the workshop.

Outcomes

The teachers did not understand basic electricity at the beginning of the workshop, but at the end, all the teachers were comfortably making voltage and resistance measurements using the digital multimeter in their kit. The lecture time on basic electricity and the time spent on the first lab activity where the teachers got familiar with making voltage and resistance measurements was time well spent.

There was a great sense of satisfaction – based on the “aahs” and “oohs” from the teachers – when standards 3.PS3.2 and 4.PS3.3 were demonstrated in the lab. In the third activity of the 3.PS3.2 standard, teachers used their DC power supply to power their TEC and witnessed the ability of the TEC to remove heat from an object. The teachers were amazed at how cold the cold side of the TEC got, as well as how quickly it got so cold. This activity was an example of testing a device that converts electrical energy to another form of energy. Even though the TEC functions like an air conditioner by removing heat from an object, in order for the TEC to do its job, it also had to convert some of the electrical energy of the power supply into thermal energy. The point being made here is that the TEC uses some of the electrical energy from the power supply to transfer heat from an object; however, it must also convert some of the power supply's electrical energy into heat just to do its job and is why this activity aligns with the standard.

There was only one lab activity for the 4.PS3.3 standard: the teachers witnessed how stored energy can be converted into another form for practical use. Considering the thermal energy of an object as a type of stored energy, a heater was used to simulate a hot object. Heat from the heater was allowed to flow over the TEG which caused a voltage to develop across the two TEG wires. This is an example of how stored energy (the thermal energy of a hot object) can be transformed into another form (voltage – which is related to electrical energy); hence, the standard was demonstrated. The two TEG wires were connected to a green light emitting diode (LED) which illuminated and is what generated all the excitement from the teachers. In addition, the teachers used the digital thermometer in their kit to measure the hot-side temperature of the TEG. This was the first time that they had used this type of digital thermometer.

Another positive outcome from the workshop was that more than 75% of the teachers were able to state the two main reasons that thermoelectrics is not ubiquitous: 1. The cost is too high. 2. The power conversion efficiency is too low.

Perhaps, the most significant positive outcome of the workshop – and an outcome that is in direct alignment with the main goal of the teachers taking the lessons learned back to their schools and familiarizing their students with TEs – is that at least one school in attendance adopted content from the workshop this fall semester. Memphis Business Academy, a STEM school in Memphis, TN with a strong commitment to teacher's professional development, student hands-on learning and participating in various student competitions, used the workshop activities to implement some of the 3rd, 4th and 6th grade standards.

Probably the biggest disappointment of the workshop was that at the end of the workshop the level of understanding of the electricity-heat analogy was less than satisfactory. This suggests that more time was needed on this topic and a specific lab exercise is needed. The disappointment comes mostly from the fact that this analogy can help one to understand so many everyday occurrences.

Workshop Survey Results

All 11 of the responding teachers stated that they would recommend the workshop to a friend or coworker. Additional proof of the workshop's effectiveness can be seen in the workshop survey results in figures 3 and 4. There were 12 teachers in attendance, and one had to leave before the end of the workshop on the second day. According to figure 3, the content was covered at an appropriate level – despite having a large grade range (i.e., grades 3 – 12). Figure 4 directly supports the claim that the workshop was effective because 9 of the 11 participants stated that the workshop's effectiveness was a 9 or 10 on a scale of 1 to 10 and 2 of the 11 participants stated that the workshop's effectiveness was an 8 out of 10.

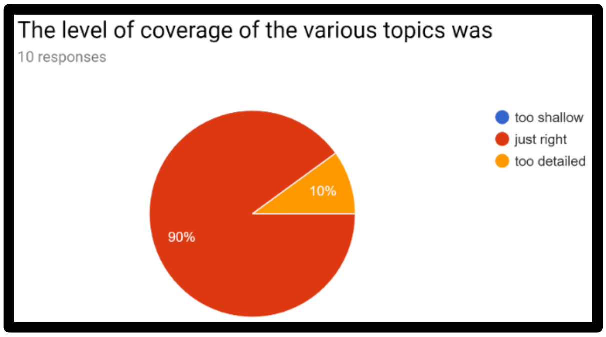

Figure 3. Response to "how was the level of coverage of the topics?"

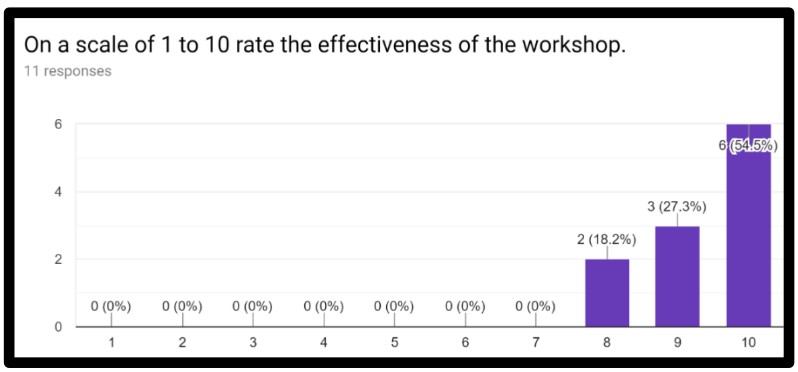

Figure 4. Teachers' ratings of the workshop effectiveness.

The additional teacher comments in table 3 also supports the claim that the workshop was effective: "I would like to expose teachers to more rigorous high-level thinking workshops like this one" is strong and supportive.

Table 3. Additional survey comments.

It was even more effective when to have us be able to efficiently explain what we did and/or the reason behind the lab or events that happened in the lab so we could be able to explain to our students or guide our students once they explain the labs.
I would like to expose teachers to more rigorous high-level thinking workshops like this one.
It had very good information
For teachers who are not familiar with the topic, the content covered may be a lot to take in and the extension of the workshop would give them more time to process new information.
I learn better when I can physically do something. I am a visual tactile learner. The workshop is well-done. So glad I can take all the instruments home. My students will enjoy more hands-on projects.

However, there is room for improvement as suggested by the comment related to teachers not familiar with the topic and that extending the workshop could help mitigate this lack of topic familiarization.

Table 4 shows the responses to the survey question "what did you like most about this workshop?" and supports the claim that the workshop was highly successful. Of special importance is the fact that the hands-on activities supported the lecture concepts and made the information more retainable. In addition, one teacher could even visualize applying the workshop knowledge to a math class.

Table 4. What did you like most about this workshop?11 responses

Hands-on with the explanation of the standards.
I like having the opportunity to participate in the hands on lab activities.
Excellent teacher, very patient
There was a lot of background/foundational information given during the lesson. The labs tied in all of that new knowledge to make sense. The hands-on activities made all that information to be more concrete and retainable.
Hands-on experience to back-up the lecture. food and beverages provided, nice and detailed instructor.
Ability to work in labs. I did like the moving back to class for the lectures. It helped with transitions being able to keep equipment!
Appreciated the detail/context. The activities supported the concepts.
The hands-on activities
Very convenient due to being allowed to park on the lot. I enjoyed the hands on activities. I also enjoyed the discussion and the instructor's ability to answer questions.
I liked the hands-on application of what we were learning during the lecture portion. Also the small group teaching moments in the lab when we came to the front for further clarity on a particular activity.
It was very hands-on and practical. I could easily see it used in all of my math classes. I liked being able to physically apply the formulas and standards that were covered.

A word about the workshop's intent is in order here: heat is a topic unfamiliar to most – even STEM teachers; hence, it is difficult for STEM teachers to be creative when developing activities related to the heat standards in the new Tennessee Science Standards. One important intent was to develop activities using non-status quo activities while simultaneously introducing an emerging alternative/renewable energy technology.

Lessons Learned

Many STEM teachers are not familiar with some of the fundamental concepts that are common to the various renewable/alternative energy technologies (e.g., electrical concepts). Prior to the workshop's commencement, the teachers were asked about their familiarity with basic electrical concepts, and all but one teacher had no previous experience with electrical concepts. As noted in the outcomes section, the lecture time on basic electricity and the time spent on the first lab activity where the teachers got familiar with making voltage and resistance measurements was time well spent. So, one cannot assume any prior basic knowledge when developing STEM training, even when the training is for STEM teachers. STEM teachers need training – perhaps, more now than ever before, in order to become informed and educated on new technologies because of the rapid rate of technology innovation.

The workshop should have been five days so that all of the standards could be demonstrated and so that the teachers could have time to reflect after each lab activity. Allowing reflection time makes sense after going back and looking at the level of detail covered in the workshop and in view of the fact that the teachers were not familiar with electrical or heat concepts.

The last notable lesson learned is that the group of STEM teachers who attended the workshop are very much like many of the university students in the following way: They prefer hands-on activities that reinforces the lectures. One of the participants even claimed to be a visual learner – a claim often heard from Engineering Technology students.

Conclusion

This TEs workshop met the main objective of familiarizing local STEM teachers with TEs and inspiring them to introduce the emerging technology to their students while covering heat and energy-relevant new Tennessee science standards. The teachers learned electrical concepts which are useful for understanding other renewable energy technologies and demonstrated an understanding of what it will take to move TEs into mainstream society (i.e., they understood that TEs needs to be more efficient and less costly). The most significant improvement needed is to make the workshop five days (vs. two) to allow all the new Tennessee science standards that were intended to be covered to actually be covered and to allow time for after-lab reflections.

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