Cool Argument: Engineering Students' Written Arguments about Thermodynamics in the Context of the Peltier Effect in Refrigeration

Sibel Erduran[1] and Rosa Villamanan[2]

ABSTRACT

In this paper, we investigate university engineering students' written arguments in the context of the thermodynamics principles involved in refrigeration. The students were given writing frames to complete reports following investigations on thermoelectric coolers, sometimes called "thermoelectric module" or "Peltier cooler". The device is a semiconductor-based electronic component that functions as a small heat pump. By applying a low voltage DC power source to a cooler, heat moves through the module from one side to the other. One module face, therefore, will be cooled while the opposite face is simultaneously heated. The task immerses students in the context of providing evidence and justifications for temperature change using general principles of thermodynamics. The context of the study provides examples on the nature of arguments in the applied field of engineering where appeals to scientific principles are made to justify the design of an industrial product. The writing frame engaged the students in the recording, analysis and interpretation of experimental data including data from a simulation program. Several lines of analyses have been conducted including the epistemic levels of students' arguments. This paper will report on one aspect of analysis focusing on the quality of students' written arguments. A simplified version of Toulmin's Argument Pattern (1958) has been used as a guiding model to investigate the written arguments. Results indicate that very few students were able to accurately interpret the experimental data and only 35% of the arguments from 31 reports were valid. Most texts used conclusions that were not derived from the evidence used. We propose some rubrics to further support the writing and evaluation of arguments.

KEYWORDS: argumentation, Peltier effect, epistemic levels, Toluminn's Argument Pattern

Introduction

In recent years, the learning and teaching of argumentation i.e., the coordination of evidence and theory to support or refute an explanatory conclusion, model or prediction (Suppe, 1998) has emerged as a significant educational goal. Of growing importance in science education is the need to educate students about how we know and why we believe in certain claims (Erduran and Jimenez-Aleixandre, 2008). The shift from what-we-know to how-we-know requires a renewed focus on how science education can promote students' skills in justifying claims with evidence. The case made is that argumentation is a critically important discourse process in science (Toulmin, 1958) and that it should be taught and learned in the science classroom. Considerable research has been carried out in argumentation in science classrooms (e.g. Erduran, Simon and Osborne, 2004; Jimenez-Aléixandre, Bugallo-Rodríguez and Duschl, 2000; Kelly and Takao, 2002; Zohar and Nemet, 2002).

Writing has been advocated as a tool in the learning of science particularly in coordinating modes of inquiry and acquisition of scientific ways of thinking (Keys, 1999) such as argumentation. Numerous researchers (e.g. Hand, Prain, Lawrence and Yore, 1999; Kelly and Takao, 2002) have been investigating students' science writing. The evidence suggests that students are not able to explain how knowledge claims are established nor how 'writing could act as an epistemological tool' (Hand, Prain, Lawrence and Yore, 1999, p. 160). In argumentation studies, Toulmin's Argument Pattern (1958) has been adapted as a model to support the writing of argument. For example, Bell and Linn (2000) adapted the Toulmin model for the design of the tool called SenseMaker. In a similar vein, researchers at Northwestern University developed a software programme called BGuILE (Biology Guided Inquiry Learning Environments) which supports the writing and justification of causal claims in science (e.g. Sandoval and Reiser, 2004).

[1] University of Bristol, United Kingdom.
Correo electrónico: Sibel.Erduran@bristol.ac.uk
[2] University of Valladolid, Spain.

The purpose of this paper is to present an investigation conducted on a subset of data collected with 130 university engineering students' written arguments in the context of the thermodynamics principles involved in refrigeration. Given argumentation is a key aspect of scientific inquiry, its place in tertiary science and engineering curriculum is critical though few research studies have focussed on tertiary education in argumentation studies (e.g. Kelly, Chen and Prothero, 2000). In this study, we aimed to better understand how argumentation can be promoted in tertiary education, particularly in the context of engineering education. Investigations into argumentation in a particular science content domain not only illustrates how the nature of science operates but also could provide indicators for how science education be better aligned with domain specific features of knowledge (Erduran, 2007). The students were given writing frames to complete reports following investigations on thermoelectric coolers, sometimes called thermoelectric module or Peltier cooler. The device is a semiconductor-based electronic component that functions as a small heat pump. By applying a low voltage DC power source to a cooler, heat will be moved through the module from one side to the other. One module face, therefore, will be cooled while the opposite face simultaneously is heated. The task context immersed students in the context of providing evidence and justifications for temperature change using general principles in thermodynamics. Engineering students carried out investigations including the use of a simulation program (Chamorro, Segovia, Villamañán, Martín and Villamañán, 2004).

Methods

Participants

This study took place in the Faculty of Engineering in a European university. Participants were 130 students of 3rd course in "Technical Thermodynamics II" subject of the academic curriculum. Students' practical work involved collaboration in groups of three or four. The final written reports were produced by each group with a total of 31 reports for the course.

Laboratory instruments used for data collection

Over 4 weeks, each student group had to study the Peltier effect, a principle that they would use in their professional future designing devices to either heating or refrigeration appliances in the industry context. The students were given the writing frame from Table 1 to complete reports following investigations on thermoelectric coolers. The device is a semiconductor-based electronic component that functions as a small heat pump. By applying a low voltage DC power source to a cooler, heat will be moved through the module from one side to the other. One module face, therefore, will be cooled while the opposite face simultaneously is heated. One of the drawbacks of experimental work is the amount of time that should spend, due to the complexity of the setups and the waiting time to achieve equilibrium conditions. Computer simulation is a complementary powerful tool in laboratory work and it allows improving the effectiveness of an interactive learning and teaching, since this allows obtaining many data in different conditions. The effects studied are made through laboratory equipment and a simulation program displayed in Figure 1.

- The laboratory equipment is R533, P.A.Hilton Ltd, U.K. This is a heat thermoelectric pump that consists of a Peltier module. This pump can be used for heating or refrigerating.
- The simulation is programmed in Visual Basic 6.0 and the screen interface is friendly, easy to understand and similar to the equipment from the laboratory to easily identify the entire element involved. This program had been developing by the university team in engineering (Chamorro, 2004).

Argumentation Scaffolds

A writing frame was produced including a set of questions to guide the use, analysis, interpretation and presentation of data and conclusions. The questions proposed are convergent and divergent with different difficulty and with an increasing abstraction degree. These questions have different purposes: (a) convergent inquiries try to promote the ability to construct

Figure 1. Laboratory equipment and simulation program.

arguments about the knowledge associated with mathematics and science. Such argumentation to converging questions are expected to hold truth value, that is, to be verifiable. For example the question of "What is the temperature of the cool side at different voltage flow?" promotes and records a convergent inquiry; (b) divergent inquiries take place in the concept domain, where the argumentation does not have truth value, which is not necessarily verifiable. Such argumentations involve a higher level of abstraction and difficulty. For example, the question "Can you identify the logic for the behaviour of what you observe?" invites the students to reason by appealing to a range of principles about thermodynamics. Thus students' written tasks were supported with a range of questions so as to enable the manifestation of a range of arguments from those that are readily derived from the use of algebraic equations to those that would require further abstraction and reasoning with qualifiers from a range of theories and principles. The questions on the writing frame are summarised in Table 1.

Table 1. Questions guiding the writing of arguments.

DATA MEASUREMENT
Data from the laboratory equipment
Data from simulation program SimBCT
DATA ANALYSIS
What is the temperature of the cool side at different voltage flow through the cell?
How did the temperature of the hot side change?
How much electric power is consumed by the cell in each case (situation)?
DATA INTERPRETATION
Can you identify the logic to the behaviour of what you observe?
What is the lowest temperature of the cell and what are the conditions for obtaining this temperature?
Do the data depend on the environmental (room) temperature or the temperature of the hot side?
Do you believe that the temperature of the cooler side should change if we do not put a heat sink with a fan to dissipating the heat from the hot side?
DATA PRESENTATION & COMMUNICATION
Write a report analysing the behaviour of TE module using information — including graphics and suitable variables — that you consider necessary.

Data sources for students' arguments

Data sources were 31 written reports produced by all groups. Examining students' answers across the inquiries of the problems can show the effect of practice on students' use of data and may show differences regarding the nature of the data as well as how well students make sense of data for variable temperature change using general principles in thermodynamics.

Approaches to data analysis

A simplified version of Toulmin's Argument Pattern (Toulmin, 1958) allowed us to carry out the analysis of the student's argued texts from the empirical data. Toulmin's framework in more depth has been used by researchers to identify the quality of argumentation in science classrooms (Erduran et al., 2004). We have emphasised the key claims made, the data used to validate the claim and the further justifications used to warrant the use of the data to make the claim. We have produced a framework based on the quality of the epistemic levels and argument quality in the written reports. Here we will provide a brief overview with respect to broad categories for the quality of the empirical data gathered by the students, validity of the argued text and the inferences made between facts and observed phenomena.

RESULTS

Description of the empirical data gathered by the students

Data are the factual background to any argument. They trace the path towards a conclusion or a claim. An example of data from a group's work is illustrated in Figure 2. During the proposed problems, students should be able to take relevant information (data, evidence) from measurements either from experiments or simulation program. Students should take in account the system variables together with their accuracy. Despite the emphasis in instruction to use the data in the right scientific-technological language, just only 19.4% of students found out the right expression of the observed phenomenon related to the thermoelectric effect.

Formal validity of the argued text

Formal validity refers to the presence of the data, warrant and claim as the key components of the argument. Without these three components as well as a logical and accurate link between these components, the text is not considered a valid argument. Only 35% of argued texts are formally valid. Most of the students used tautologies, propositions and ambiguous sentences. Examples of students' arguments are illustrated in the following paragraphs.

Example 1: Peltier effect as a warrant

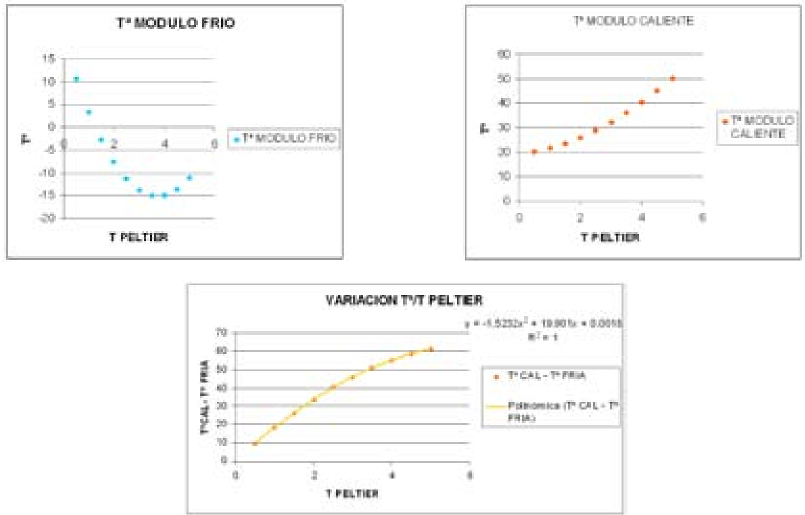
The following is an excerpt from a student's written report:

> In the previous tables (tables I and II) we can observe how the temperature changes similarly between the cold and the hot side of the cell. One can realize that when we increase the applied voltage, we increase the absolute value of both sides, this is, the hot side increases its temperature and the cold side decreases its temperature. According to this/therefore, the flow heat that can be profited increases (in this case the heat is dissipated by a suitable heat sink attached to hot side). This is due to Peltier effect, according to this, the heat has been produced depending on the voltage (or the intensity) and a coefficient.

In this example, we identified the main claim of the argument as that "*the heat that has been produced depends on the voltage or the intensity and a coefficient*." The Peltier effect is used as a

Figure 2. Data from student work.

V PELTIER(v)	*Tª CAL - Tª FRIA*
0,5	9,57
1	18,38
1,5	26,43
2	33,71
2,5	40,23
3	46
3,5	51
4	55,23
4,5	58,71
5	61,43



justification or warrant for this claim. When the student writes, "In the previous tables (tables I and II) we can observe how the temperature changes similarly between the cold and the hot side of the cell. One can realize that when we increase the applied voltage, we increase the absolute value of both sides, this is, the hot side increases its temperature and the cold side decreases its temperature", he is referring to the empirical data from his experimental work. In summary, in this example, there is an argument with a main claim, reference to empirical data and a warrant to justify how the data relate to the main claim.

Example 2: Algebraic equation as a claim

In this example, the experimental data are used to substantiate a claim made through a common algebraic equation in the conceptual domain.

> *The value of the lower temperature depends on the temperature of the hot side. When we apply a voltage, a difference of temperature between both sides is created, not a fixed value of temperature. Therefore, D_T has a determinate value for each value of the voltage. That is, if the hot side has a high temperature (as the D_T is fixed), the cold side will be a higher temperature than if the hot side has a lower temperature. Then increasing the temperature of the hot side means that the temperature of the cold side will be higher for a determinate voltage $D_T = T_h - T_c = cte$.*
>
> *In summary,*
>
> *The higher T, the T_{cold} ; The lower T_{hot}, the T_{cold}*

Here the main conclusion is that "increasing the temperature of the hot side the temperature of the cold side will be higher for a determinate voltage $D_T = T_h - T_c = cte$". The student is using "the value of the lower temperature depends on the hot side's temperature" as a warrant and "DT has a determinate value for each value of the voltage" as data.

Analysis of the inferences made between facts and observed phenomena

Throughout the text, from the initial thesis to the final conclusion there needs to be coherence in order to validate the whole argument. Facts are established from experimental data having a meaning in the conclusions due to laws, theories, principles, models and so on. Hence concordance between experimental evidence and established conclusions were analyzed in the students' inferences. Conclusions were made from three different points of view: (a) a theoretical view inserted in a scientific context; (b) the experimental facts themselves; (c) a descriptive account. Only 35% of argued texts present a concordance between facts and conclusions (e.g. Figure 3). Most of the texts used evidence that did not reach the conclusions using the evidence. For example, as illustrated in Figure 4 (from one report consisting of the main claim, the experimental data used and the justification for the conclusion) many students' arguments did not connect the experimental data and any theoretical warrants to justify the conclusions reached. Instead, the main claims made were irrespective of the data collected. The warrants used were repetitions of formulae used in the content domain but not necessarily leading to the conclusions reached in the particular example.

Design of rubrics to support writing and evaluation of arguments

The results of the study suggest that the writing frame with the questions provided to the students (Table 1) to facilitate their writing needs to be supplemented with further

Figure 3. Example of data and warrants being used to justify the conclusion reached.

Conclusion

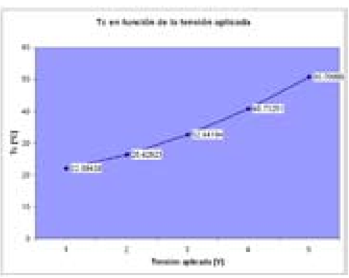
The observed behaviour is logical, since when the voltage is higher in the Peltier cell, $\Delta T^a(T_c - T_f)$ is higher, and to increase T_c, as we have seen in b section, higher should be the heat that must be dissipated at hot side, so a high intensity that flow

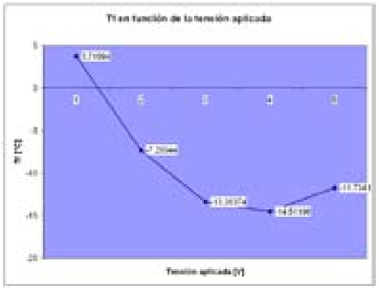
Ley de Kirchoff $\longrightarrow$ $V = I \cdot R$ / R = cte. $\longrightarrow$ $\uparrow V - \uparrow I$

Therefore, it is consistent with the consumed power to be higher.

Experimental data

Medición	$V_{mód}$ [V]	$I_{mód}$ [A]	T_c [°C]	T_f [°C]
1	1	2,9	22,09438	3,71094
2	2	8	26,42923	– 7,28944
3	3	8,7	32,64194	– 13,36374
4	4	11,6	40,73251	– 14,51196
5	5	14,5	50,70095	– 11,7341





$\uparrow$ Tensión $\longrightarrow$ $\uparrow$ Potencia

$\uparrow$ Potencia $\longrightarrow$ $\uparrow T_c$ $\longrightarrow$ $\downarrow T_f$

Justification or warrant

At practical level, due to the loss by the heat transferred between the cell and refrigeration fin, it is difficult to get the thermal jump. Neither does it have a linear performance and there are very heavy elements, so the working performance obtained is very low.

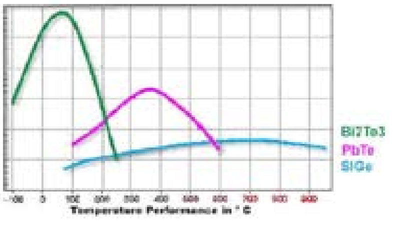


Figure 4. Conclusion reached being disconnected from data and warrant.

Conclusion

The main use of Peltier cell are as refrigerant, therefore must be the cold side to the lowest temperature possible, we can get this dissipating heat from hot side with the higher performance possibly in a fun manner! In this respect, the results are environmentally important since at hot room temperature we will have a higher T_{heat} and higher $T_{cold.}$ That is what we don't want that are that cold side make a refrigeration higher possible.

Experimental data

Los datos obtenidos por simulación son los siguientes:

Tensión(V)	Intensidad(A)	Tcaliente(°C)	Tfrio(°C)	ΔT	Potencia consumida(W)
0	0	19,8	19,8	0	0
1	2,9	22,728	4,344	18,384	2,9
1,5	6,525	24,66	-1,772	26,432	9,7875
2	11,6	27,063	-6,656	33,719	23,2
2,75	17,125	31,07	-12,14	43,21	47,09375
3	26,1	33,275	-12,731	46,006	78,3
3,5	35,525	37,086	-13,921	51,007	124,3375
4,375	58,125	44,41	-13,5	57,91	254,296875
5	72,5	51,334	-10,101	61,435	362,5

Justification or warrant

En cuanto a la cesión y absorción de calor en los bloques debido a la aplicación de una tensión en la célula cumplen la siguiente relación:

$Q_{TC} = 2\alpha\, T_C\, I$ poder termoeléctrico calentando
$Q_{TF} = 2\alpha\, T_F\, I$ poder termoeléctrico enfriando.

Donde:

T_C: es la temperatura de la cara caliente.
T_F: la temperatura de la cara fría
α: es el coeficiente Seebeck
I: la corriente que atraviesa al circuito.

Y el flujo neto de calor intercambiado el siguiente, según las expresiones anteriores

$$P = Q_C - Q_F = \alpha (T_C - T_F)\, I = \alpha \Delta T\, I$$

Por tanto para modificar la temperatura en el lado caliente T_C depende de la intensidad que atraviesa el circuito y del coeficiente de Seebeck.

scaffolds in order to improve the quality of students' arguments. Given that most issues related to the quality of the formal validity of an argument and the inferences made between the components of an argument, we consider that explicit support of these aspects would help to improve students' writing. Hence we have devised a rubric (Table 2) to supplement the report writing. The rubric again uses the Toulmin model to target particular aspects of argument and are accompanied by a set of questions that the students can reflect on with respect to their own data collection and interpretation. There is also a section on evaluation of the feature of argument suggesting the self- and peer- assessment of the arguments produced in groups.

Conclusions and educational implications

The study presented illustrates engineering students' written arguments in the context of Peltier effect in thermodynamics of refrigeration. The particular task context provides examples for the nature of arguments in the applied field of engineering where appeals to scientific principles are made to justify the design of an industrial product. The results highlight the difficulties that tertiary students face with the writing of arguments. Considering that the student sample in the study were third year engineering students, it is particularly surprising that the majority of the conclusions were not derived from the experimental evidence despite the questioning support provided for the writing of the final report. The result provide some indicators for guidelines as to how future support structures could be designed to help students in their collection, analysis, interpretation and presentation of experimental evidence. For instance, we have illustrated how an evaluation rubric could supplement students' writing. The study has implications for how students can be introduced to the writing of arguments in science and engineering contexts earlier on in their education in order to minimise difficulties at a more professional level. As the task context illustrates, understanding the rationale for and the structure of argument are prerequisite to tertiary students' satisfactory performance in both basic and applied science. These skills are unlikely to be acquired effectively at university level without any earlier background on scientific reasoning with argument.

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Table 2. Rubric to support and evaluate written arguments.

Feature of arguments	Analysis criteria	Scores (0 = minimum, 2 = maximum)
Formal validity	Are the essential components of an argument (claim, data, warrant) **present** and are they **accurate**?	
Structure of reasoning	Are there multiple lines of **reasoning**? What are the different lines of reasoning?	
	Are the lines of reasoning **plausible** given the scope of the thesis?	
	Do the lines of the reasoning **converge** to a conclusion?	
Observational data	Are the data **appropriate**? Are they based on or derived from observation?	
	Are the data presented in the right **scientific language**?	
	Are the representations well **expressed**?	
	Are the data used **relevant**?	
	Are the data **sufficient** to reach the conclusion?	
Warrants	Do the warrants used **relate** to the data and the conclusions?	
	Are the warrants used to **justify** the use of data to reach the conclusion?	
	How are the warrants related to backings? Are there any backings to **support** and **justify** the warrants?	
Qualifiers	Are qualifiers **used**?	
	Are qualifiers used of different **kinds**?	
Conclusion	Are the inferences valid made between the data and the conclusion **valid**?	
	Is the conclusion supported by the data, warrants and backings?	

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