CONSTRUCTIVIST PRINCIPLES AS USED FOR ENHANCING ACTIVE LEARNING – CASE: ENGINEERING THERMODYNAMICS

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ABSTRACT

Engineering Thermodynamics is an important engineering discipline in universities, concerned mainly with traditional and alternative sources of energy in terms of availability, movement, and conversion. However, much discontent can be found in the literature regarding teaching deficiencies and recognized learning difficulties associated with this subject. Many attempts have been tried, such as the blended learning approach, active learning techniques, computer-based instruction, critical thinking enhancement and the use of technology such as a virtual laboratory. In the present contribution, the principles of the constructivist approach are integrated in order to enhance students' active learning. This is very relevant when using the CDIO approach which emphasizes active learning (CDIO Standard 8). The new constructivist learning elements include a much greater emphasis on coaching, scaffolding, and modelling. The improvement of student learning and retention of concepts after integrating the principles of the constructivist approach is measured using a pre- post-assessment experiment. The findings encourage engineering educators and educational institutions to prefer constructivist principles over traditional principles to (1) increase more effectively students' interest in Engineering Thermodynamics, (2) ensure more effective learning of the general understanding of Engineering Thermodynamics, and (3) support more effectively students' learning of knowledge and skills required to solve more difficult Engineering Thermodynamic problems.

KEYWORDS

Constructivist principles, Learning effectiveness, Active learning, Thermodynamics, CDIO Standard: 8.

INTRODUCTION

Thermodynamics is taken by students in the majority of university engineering programs, mechanical, chemical, civil and electrical, as well as by students studying physics and chemistry, although with some variations in the topics covered, depending on the discipline involved. Often in an engineering program, thermodynamics comes early, possibly in the second or even first year of a four-year course, as it teaches fundamental concepts and acts as a pre-requisite for other later courses. Manteufel (1999) has described thermodynamics as the 'gateway' course in mechanical engineering in the sense that students' performance in the subject is in good correlation with how the students do in the rest of the courses in the curriculum. However, the fundamental concepts within engineering thermodynamics are quite often considered difficult to grasp by students. Students' expressions of dissatisfaction and frustration are very common (Cobourn & Lindauer, 1994; Meltzer, 2006; Grigull, 1990) as is evidence of widespread poor learning of basic concepts and principles of thermodynamics by university students (Lape, 2011; Abulencia *et al.*, 2012; Meltzer, 2004; Loverude *et al.*, 2002; Prince *et al.*, 2009; Jasien & Oberem, 2002). There is even a culture of simply accepting the status quo by students who make remarks like 'one cannot understand thermodynamics, only get accustomed to it' (Grigull, 1990).

This last remark may well give a clue as to what should be included in an introductory course to engineering thermodynamics. It indicates a desire on the student's part for proofs of the axioms of thermodynamics, i.e. the principles, which in fact do not exist. The issue of how the validity of the principles can be established is an old and familiar problem for the theory of cognition. Deduction could be used, but this may not always correspond with reality. Another way is to use refutability, which, to a student may prove frustrating as there is no final prove except by constant refutation. Basically, the principles of thermodynamics form a reliable basis of our knowledge simply because all our efforts have failed to refute the principles. This is a difficult logical structure for students new to thermodynamics to grasp. This is particularly true since the degree to which the principles of thermodynamics influence daily life, as well as many areas of applied sciences, cause students to perceive them as 'long-proven' laws of nature (Grigull, 1990). The students must simply 'get accustomed' to the fact that the principles are empirical and by their nature cannot be proven; and that they are only a reliable basis for our understanding and use as long as it has not been possible to refute them, but that such a possibility remains open. Such a concept is far removed from the 'naïve' approach of many students (Grigull, 1990). From this, it could be deduced that in a first course in thermodynamics the students should be made aware of the general fundamentals, the most important applications such as the principles, the equation of state and the various cycles. Only in a later course can the logical structure of thermodynamics including the concepts of thermodynamic potential and thermodynamic consistency be introduced.

This is especially true within a CDIO learning environment where the emphasis is on active learning (CDIO Standard 8). Here students need to master the basic concepts of thermodynamics in order to be able to design solutions to applications where a deep knowledge of thermodynamic theory, and especially the first and second laws, is needed.

The purpose of this research is to explore how the principles of constructivism can help where pedagogical constructivism is used and 'is concerned with the teaching and learning process with particular attention to the knowledge constructed within the learner, differentiated for each learner (Wink, 2014).

In the paper, a brief discussion concerning the advantages and disadvantages of using a pedagogical constructivist approach in general is followed by a detailed description of what was involved in applying such an approach to the teaching and learning of engineering thermodynamics. There then follows an extensive experiment investigating if such an approach is of benefit to the student learning, especially the student learning and retention of what can be quite abstract laws and principles found in engineering thermodynamics.

THE PEDAGOGICAL CONSTRUCTIVIST APPROACH

The emergence of constructivism as the prominent learning theory in colleges and universities has resulted because of the movement from behaviorism to cognitivism and now the constructivist perspective (Cooper, 1993). Behaviorism stresses performance acquired by short-term learning techniques designed to pass tests and accomplish tasks. The problem that arises is that after a period of time students can no longer remember or apply what has been learned. Instruction is teacher-centered and accomplished in a didactic manner with much teacher-talk, disseminating information to the passive recipients. Other aspects of traditional classrooms primarily include (1) over-reliance on textbooks which generally only offer one worldview, (2) discouragement of cooperation which leads to higher order reasoning that working in isolation limits, and (3) seeking correct answers instead of allowing students to work through intricate issues which would result in knowledge construction and deep learning. Constructivism emphasizes knowledge construction in contrast to knowledge transmission along with the mainly passive recording of information transferred by a teacher, instructor or lecturer. Construction of knowledge can be facilitated in educational student-centered environments that encourage students to appreciate uncertainty, inquire responsibly and search for understanding (Brooks & Brooks, 1999). Through the processes of self-reflection and questioning, analyzing, evaluating and problem-solving learners become active and independent constructors of knowledge (Wink, 2014; Cooper, 1993). Thus, from a constructivist theoretical viewpoint 'learning' produces long-term understanding while 'performance' culminates in limited recollection of concepts as time goes on.

Brooks and Brooks (1999) declare that learning and education should be a time of curiosity, exploration and inquiry and that memorization must take a secondary role. Learning how to solve real-world problems by constructing new knowledge through the critical process of creativity and implementation of original ideas supersedes memorization and repetitious reproduction of existing knowledge and concepts. Constructivism acknowledges the importance of prior knowledge and experience and learning is an ever-evolving growing process, and not only an accumulation of knowledge (Proulx, 2006). Instead, cognitive development must ensue and result in individual constructions of understanding. In traditional learning environments if learners can learn procedures and reproduce chunks of information then the perception is that learning has taken place. From a constructivist perspective 'imitative behavior' is not what is required; deep learning is the goal and is demonstrated by what students can 'generate, demonstrate or exhibit' (Brooks & Brooks, 1999). It becomes apparent that traditional teaching to a large extent is inadequate and needs to be replaced by the constructivist paradigm which encourages active construction of meaning that produces concept development, deep understanding, structured knowledge acquisition, and which fosters higher levels of autonomy (Beerenwinkel & von Arx, 2016).

The general consensus among educators worldwide is that thermodynamics is challenging and difficult to understand; this results in two major areas of concern: Poor achievement and retention of knowledge (Mulop *et al.*, 2012). Therefore, research engaged in enhancing teaching and learning for this subject is relevant and needful. In a study conducted with undergraduate thermodynamics students, it was concluded that the most important factor when teaching this subject is to determine what the student already knows, what prior knowledge they have and to then teach accordingly (Holman & Pilling, 2004). The blended learning approach (Bullen & Russell, 2007), active learning environment (Hassan & Mat, 2005), computer-based active learning materials (Anderson *et al.*, 2002), as well as modelling, scaffolding and coaching (Jonassen *et al.*, 1993; Jonassen, 2009) proved to be effective methods of enhancing teaching and learning in thermodynamics (Mulop *et al.*, 2012) and increasing interest without forfeiting rigor or quality (Brooks & Brooks, 1999).

Active learning, knowledge construction, collaborative learning, coaching, scaffolding and modelling are all consequential constructivist teaching pedagogy components for enhancing the learning of thermodynamics for engineering students. Active learning is characterized by student-centered collaborative learning environments wherein learning is not passively transmitted. Students ask themselves questions, analyze, reflect and work on problems and actively construct knowledge individually and in groups. Learning is an active process wherein students autonomously take responsibility for their education to a large extent (Hessenauer *et al.*, 2019). The scaffolding component requires active involvement; support given depends on what the learner already knows and what the learner is capable of accomplishing with the support of the more knowledgeable interlocuter (instructor or peer). Over time support is slowly withdrawn or minimized until the student is able to take responsibility for learning. As previously stated above, a good starting point is to assess the current knowledge of the students. Questions such as: Do you know what to do; have you done a problem like this before; will your past experience help you solve this problem (Holton & Clarke, 2006)? Once the instructor has determined the level of support which is needed there are several options which include (1) feeding back, (2) hints, (3) instructing, (4) explaining, (5) modelling and (5) questioning (Van de Pol *et al.*, 2010). For example, the instructor provides small pieces of information or makes suggestions (hints) to students who are working on solving problems – just sufficient to keep the process moving forward but not too much to interfere with autonomy (Hessenauer *et al.*, 2019). ‘Hints’ could also be described as “coaching” with regard to scaffolding. Modeling is another scaffolding strategy, where expected behavior, skills or knowledge is demonstrated in a Vygotskian inspired way (Van de Pol *et al.*, 2010). Participants are both active participants and build “common understanding or intersubjectivity through communicative exchanges in which the student learns from the perspective of the more knowledgeable other” (Van de Pol *et al.*, 2010). This is known as the Zone of Proximal Development (ZDP) which enables a student’s developmental growth with scaffolded support to ensure that the learner can accomplish learning goals which could not be achieved alone. For the focus of this study, scaffolding will refer to face-face communications with a specific emphasis on student-teacher interactions. This in contrast to types of support offered that do not involve active interactions. The purpose of the clarification is to appease opponents (Pea, 2004; Puntambekar & Hübscher, 2005) who claim that the theoretical context has been lost and that scaffolding has become a synonym for support (Van de Pol *et al.*, 2010).

The components of the behavioral framework as presented in Table 1 are powerful descriptors which if applied can improve instruction and result in improved performance and retention of knowledge. Accepting and encouraging autonomy is a critical component of constructivist teaching. Once questions have been posed or problems assigned, the instructor must provide sufficient ‘wait time’ in addition to the acknowledgement of student autonomy, to ensure the development of critical thinking ability and discovery (Hessenauer *et al.*, 2019). The opportunity for students to discern in a transformation-seeking classroom where students seek connections between ideas and concepts will provide learner autonomy and initiative (Brooks & Brooks, 1999). The development of autonomy necessitates the need to provide enough time for the completion of challenging problems and questions. A better approach to asking questions or posing problems is to allow group discussion and then to later give the groups the opportunity to give whole group feedback. Furthermore, in order to stimulate mental activity, it is important to frame tasks generated from Bloom’s Taxonomy so as to generate new understandings and constructions of knowledge. Lexis such as design, develop, investigate (create); appraise argue, judge critique (evaluate); relate, contrast, examine, experiment (analyze); and solve, demonstrate, interpret (apply) will facilitate constructions of new understanding. In addition, dialectical or social constructivism which emphasizes discussion, sharing and debate among learners is critical to the construction of new understanding (Rogoff, 1990). Students collaborate in small groups helping others find meaning while refining their own (Applefield *et al.*, 2001). Teacher-student and student-student social negotiation are essential for the emergence of multiple perspectives, reflection, the advocacy of ownership of learning, and self-awareness (Hessenauer *et al.*, 2019). Moreover, instructors use social interaction to scaffold tasks enabling students' understanding of difficult concepts using various strategies as discussed above.

Table 1. Constructivist Teaching Behavior Framework

1	Constructivist teachers accept and encourage student autonomy and initiative.
2	Constructivist teachers use raw data and primary sources.
3	When framing tasks constructivist teachers use cognitive terminology such as classify, analyze, predict and create etc.
4	Constructivist teachers allow student responses to drive lessons, shift instructional strategies and alter content.
5	Constructivist teachers inquire about students' understandings of concepts before sharing their own understandings of those concepts.
6	Constructivist teachers encourage students to engage in dialogue, both with the teacher and with one another.
7	Constructivist teachers encourage student inquiry by asking, thoughtful, open-ended questions and encouraging students to ask questions of each other.
8	Constructivist teachers seek elaboration of students' initial responses.
9	Constructivist teachers engage students in experiences that might engender contradictions to their initial hypothesis and then encourage discussion.
10	Constructivist teachers allow waiting time after questions.
11	Constructivist teachers provide time for students to construct relationships and create metaphors.
12	Constructivist teachers nurture students' natural curiosity through frequent use of the learning cycle model.

More recently, strong evidence has been provided that the implementation of Virtual Reality (VR) in engineering education is compatible with the constructivist learning environment (Soliman *et al.*, 2021). Similarly, and based on a systematic literature review of 154 studies related to single-board computers in engineering and computer science education, the support of a constructivist learning environment by single-board computers has been confirmed by Ariza & Baez (2022). Finally, a positive impact on constructivist learning environments has been reported over the last years by applying educational games and simulations (Gamarra, *et al.*, 2022).

TEACHING AND LEARNING EVALUATION - A CONTROLLED EXPERIMENT

The constructivist approach to teaching and learning engineering thermodynamics was evaluated using a controlled experiment which comprised the application of a pre-test post-test control group experiment (Pfahl *et al.*, 2004). The students from each group, the experiment group (A), i.e., those who were taught using the constructivist approach, and the control group (B), i.e., those who were taught using the traditional delivery method of lectures, tutorials and laboratories, had to undertake three tests, one before their respective courses (pre-test) and two after their respective courses, one immediately after the finish of the course and one month later, to assess student learning and also retention of concepts taught. The performance of the two groups were measured using six constructs, with each construct represented by one independent variable. Each dependent variable has the hypothesis:

1. There is a positive learning effect in both groups (A: experimental group, B: control group). That is to say, the post-test scores taken immediately after the course are significantly higher than pre-test scores for each dependent variable.
2. The learning acquired during each course (and tested immediately after each course finished; Post-test1) is shown to be more effective for group A than for group B, either with regard to the performance improvement between the respective pre-tests and post-tests (i.e., the relative learning effect), or with regard to the post-test performance (absolute learning effect). The absolute learning effect is of interest because it may indicate an upper bound of the possible correct answers depending on the method of teaching.
3. Retention of the learning during each course (and tested one month after each course had ended; Post-test2) is shown to be more effective for group A than for group B, either with regard to the performance improvement between the respective pre-tests and post-tests (i.e., the relative learning effect), or with regard to the post-test performance (absolute learning effect).

Consequently, the Null hypotheses are stated as follows:

$H_{0,1}$: There is no difference between Pre-test scores and Post-test1 scores within experimental group (A) and control group (B).
$H_{0,2a}$: There is no difference in relative learning effectiveness between experimental group (A) and control group (B) immediately after the finish of the course.
$H_{0,2b}$: There is no difference in absolute learning effectiveness between experimental group (A) and control group (B) immediately after the finish of the course.
$H_{0,3a}$: There is no difference in relative retention between experimental group (A) and control group (B) using the results of Post-test2 and the Pre-test.
$H_{0,3b}$: There is no difference in relative retention between experimental group (A) and control group (B) using the results of Post-test2 and Post-test1.
$H_{0,3c}$: There is no difference in absolute retention between experimental group (A) and control group (B) using the results of Post-test2.

The design began with the assignment of students to the experimental group (A) and control group (B) using a pairing system based on students' GPA. The aim, during the formation of groups, was to produce teams having as close as possible equal average GPAs, and having within each group a mixed GPA where the GPA range was, as close as possible for each group. It is well recognized that although having homogeneous groups (i.e. the group members having an almost equal GPA) can increase teamwork satisfaction and possibly enhance overall course and learning satisfaction compared with mixed GPA groups, the overriding purpose of the group formation was to be able to compare like with like. This was followed by members of each group completing a pre-test. This measured the performance of the two groups before the delivery of the courses. In all three tests, i.e., the pre-test, the post-test immediately after finishing the course and the post-test one month after finishing the course, the questions were identical, although this was never mentioned to the students. Also, no questions from the tests were ever allowed to be retained by the students.

Due to the fact that an experiment comparing results of the traditional approach with those of the constructivist approach was to be conducted, the implementation, assessment and delivery had certain similarities, to try to avoid possible bias. The contact hours for both approaches were the same although the breakdown of the different teaching methods within each approach did differ. For example, there was much more formal lectures given in the traditional approach and less discussion periods. Both approaches had a lead Instructor (Professor) supported by two teaching assistants full-time. Again, trying to have no bias in the comparison between traditional and constructivist approaches the assessment methods which contributed to a student's grade were very similar and consisted of assignments, lab assignments, major lab reports and various groups activities. There was also a formal mid-term multiple choice test and final examination for each group containing the same questions.

The students were in the 2nd year, second semester of a four-year mechanical engineering course with the number of students in group A, NA = 38, and in group B, NB = 34. The numbers in the group could be considered as small but there is ample evidence in the literature that the numbers can be considered as sufficient, e.g., rule of thumb: at least 30 subjects suggested by (Hauschildt & Hamel, 1978) and the survey results did not change significantly when the sample size became larger than 20 (Zahn, 1993). The uneven group sizes was because two students insisted on being in the constructivist group rather than the traditional group and using the principle that everything was voluntary, this was agreed to. The characteristics for both sets of students are summarized in Table 2.

Table 2. Student personal characteristics

Characteristics			
	Overall Cohort	Group A	Group B
Average age [years]	20.5	20.4	20.6
Percentage female [%]	23	21	25
Engineering major	Mech. Eng.	Mech. Eng.	Mech. Eng.
Preferred learning style [% of students in group]			
Reading with exercise	8	10	6
Lecture	9	11	7
Tutorial	15	16	14
Laboratory	20	23	17
Group work	18	18	18
Individual projects	16	14	18
Group projects	14	8	20
Opinion of most effective learning style [% of students in group]			
Reading with exercise	9	10	8
Lecture	7	9	5
Tutorial	12	12	12
Laboratory	18	19	17
Group work	16	17	15
Individual projects	20	19	21
Group projects	18	14	22

It can be seen from Table 2 that there is a close correlation between the students' preferred learning style and what they thought to be the most effective learning style for them. Also, it could be argued that students do want to be more actively engaged in their learning with possibly the most active learning, that of being in the laboratory, the most popular.

Data collection

Data for the dependent variables (J.1, …, J.4) were collected with the variables' details listed in Table 3.

Table 3. Experimental variables

Dependent variables
J.1 Interest in Engineering Thermodynamics ('Interest')
J.2 General knowledge of Engineering Thermodynamics ('General')
J.3 Knowledge and skills sufficient to solve 'simple' Engineering Thermodynamics problems ('Simple')
J.4 Knowledge and skills sufficient to solve 'difficult' Engineering Thermodynamics problems ('Difficult')

The dependent variables are constructs used to capture aspects of learning provided by the courses and each was measured using five questions. The questions can be characterized as:

J..1 ('Interest'): Questions about personal interest in Engineering Thermodynamics.
J.2 ('General'): Questions to elicit how much students understand the role of Engineering Thermodynamics in the professional engineering area as found today.
J.3 ('Simple'): Technical questions concerning Engineering Thermodynamics that require fairly elementary knowledge and skills.
J.4 ('Difficult'): Technical questions concerning Engineering Thermodynamics that require a much deeper knowledge and skills.

The results for the dependent variable J.1 were found by applying a five-point Likert-style scale (Likert, 1932) with each answer mapped to the value range R = [0, 1]. The values for variables J.2-J.4 are average scores derived from the five questions for each category. Missing answers were marked as incorrect.

RESULTS AND DISCUSSION

The descriptive statistics are summarized in Table 4 where the columns 'Pre-test scores' and Post-test scores showing the calculated values for mean ($\bar{x}$), median (m) and standard deviation (σ) of the raw data collected, and the columns under 'Difference scores' shows the differences between the Post-test1 and pre-test scores, as well as the differences between the Post-test2 and the Post-test1 scores, and, the Post-test2 and pre-test scores. In line with the value range for the average test scores, the difference scores are on a value range R = [0, 1].

Table 4. Scores of dependent variables

	Pre-test scores				Post-test1 scores				Post-test2 scores			
	J.1	J.2	J.3	J.4	J.1	J.2	J.3	J.4	J.1	J.2	J.3	J.4
Group A												
($\bar{x}$)	0.78	0.71	0.40	0.36	0.79	0.86	0.45	0.50	0.79	0.85	0.44	0.50
(m)	0.81	0.65	0.39	0.33	0.83	0.79	0.51	0.41	0.82	0.78	0.49	0.40
(σ)	0.12	0.32	0.27	0.24	0.11	0.24	0.16	0.20	0.12	0.24	0.16	0.19
Group B												
($\bar{x}$)	0.86	0.61	0.46	0.29	0.87	0.67	0.48	0.41	0.86	0.65	0.48	0.41
(m)	0.83	0.63	0.43	0.27	0.86	0.66	0.44	0.31	0.85	0.63	0.44	0.30
(σ)	0.12	0.25	0.20	0.12	0.21	0.19	0.18	0.11	0.21	0.21	0.18	0.12
	Difference scores (Post-test1 - Pre-test)				Difference scores (Post-test2 - Pre-test)				Difference scores (Post-test2 - Post-test1)			
	J.1	J.2	J.3	J.4	J.1	J.2	J.3	J.4	J.1	J.2	J.3	J.4
Group A												
($\bar{x}$)	0.11	0.15	0.05	0.14	0.01	0.15	0.04	0.14	-0.01	0.00	-0.01	0.00
(m)	0.01	0.14	0.12	0.08	0.01	0.13	0.10	0.07	0.00	-0.01	-0.02	-0.01
(σ)	0.12	0.18	0.22	0.21	0.11	0.18	0.22	0.15	0.11	0.19	0.23	0.20
Group B												
($\bar{x}$)	0.01	0.06	0.02	0.12	0.00	0.05	0.02	0.12	-0.01	-0.02	0.00	0.00
(m)	0.02	0.03	0.01	0.04	0.01	0.00	0.01	0.03	-0.01	-0.02	0.00	-0.01
(σ)	0.10	0.18	0.26	0.18	0.13	0.18	0.27	0.20	0.09	0.19	0.27	0.15

For $H_{0,1}$ and focusing on the experimental (constructivism) group (A) and for the control group (B), Table 5 shows the results when using a one-tailed t-test for dependent samples. Column one, specifies the variable, column two represents the Cohen effect size, d, column three, the degrees of freedom, column four, the t-value of the study, column five, the critical value for the significance value $\alpha=0.10$ and column six lists the associated p-value (Pfahl *et al.*, 2004). Using the suggestions of Pfahl *et al.* (2004), testing for the normality assumption, analysis to detect outliers and the non-parametric tests of the Wilcoxon and the Mann-Whitney U-test were carried out for the null hypotheses, and it was found that no normal distribution of the variables could be assumed and that all the data lay within the +/-2 standard deviations around the samples' means. The non-parametric tests did not show any difference from the results of the t-tests.

The results show that the Post-test1 scores of J.2 and J.4 are significantly larger than the Pre-test scores for Group (A). with ; whereas only Post-test1 scores of J.4 were significantly larger than the Pre-test scores for Group (B).

These results reflect evidence that general knowledge about Engineering Thermodynamics is more effectively learnt using constructivist principles. Furthermore, both pedagogic approaches, using constructivist principles and using more traditional principles, are suitable to learn effectively knowledge and skills necessary for solving difficult Engineering Thermodynamic problems. Therefore, based on the differences between Post-test1 and Pre-test scores of the variables considered here, constructivist principles constitute a more effective learning approach.

Table 5: Results for ‘post-test1’ versus ‘pre-test’ for groups (A) and (B).

Group (A): Experimental					
Variable	d	df	t-value	Crit. $t_{0.90}$	p-value
J.1	0.09	37	0.41	1.31	0.342
J.2	0.53	37	2.24	1.31	0.057
J.3	0.21	37	0.90	1.31	0.188
J.4	0.65	37	2.83	1.31	0.004
Group (B): Control					
J.1	0.08	33	0.31	1.31	0.379
J.2	0.29	33	1.18	1.31	0.123
J.3	0.12	33	0.48	1.31	0.318
J.4	1.04	33	4.38	1.31	0.000

Following the same approach for the remaining hypotheses $H_{0,2a}$ to $H_{0,3c}$, for $H_{0,2a}$ and based on the difference scores for Post-test1 – Pre-test (Table 4), it was found that the difference scores for J.1 and J.2 are significantly larger for group (A) than for group (B) (Table 6).
These results reflect that constructivist principles lead to a more effective increase in interest in Engineering Thermodynamics and to a more effective learning of general knowledge related to Engineering Thermodynamics, compared with traditional learning approaches.

Table 6: Results for ‘performance improvement’ for group (A) versus group (B).

Variable	d	df	t-value	Crit. $t_{0.90}$	p-value
J.1	0.87	71	3.68	1.29	0.000
J.2	0.48	71	2.01	1.29	0.024
J.3	0.10	71	0.43	1.29	0.336
J.4	0.12	71	0.50	1.29	0.310

To test $H_{0,2b}$ and using the absolute results for Post-Test1 (Table 4), it was found that scores of J.2 and J.4 are significantly larger for group (A) than for group (B) (Table 7). The scores of J.1 are significantly larger for group (B) than for group (A).
This means, the absolute learning effectiveness immediately after finishing the course and related to the learning of general knowledge of Engineering Thermodynamics and of knowledge and skills required to solve difficult Engineering Thermodynamic problems, is higher when using constructivist principles. However, different from the previous interpretation of the relative change of interest in Engineering Thermodynamics, the absolute interest in Engineering Thermodynamics is higher when using traditional approaches. This might be related to the effect of an excited lecturer when presenting videos and photographs related to Engineering Thermodynamics. However, general knowledge of Engineering Thermodynamics and knowledge and skills required to solve difficult Engineering Thermodynamic problems, as well as a more pronounced increase in interest in Engineering Thermodynamics when using constructivist principles, are arguably more important than the absolute interest in Engineering Thermodynamics.

Table 7. Results for 'post-test improvement' for group (A) versus group (B). (bracket value means result goes against the hypothesis)

Variable	d	df	t-value	Crit. $t_{0.90}$	p-value
J.1	(0.47)	71	2.04	1.29	0.023
J.2	0.84	71	3.55	1.29	0.000
J.3	(0.21)	71	0.88	1.29	0.191
J.4	0.56	71	2.35	1.29	0.011

To test $H_{0,3a}$ and using the difference scores between Post-test2 and Pre-test (Table 4), it was found that the difference scores of J.2 are significantly larger for group (A) than for group (B) (Table 8). To test $H_{0,3b}$, and using the difference scores between Post-test2 and Post-test1 (Table 4), it was found that no significant difference exists between the two groups (Table 8).

Adding to the interpretation of the higher relative learning effectiveness of general knowledge of Engineering Thermodynamics when finishing the course, the results here show that constructivist principles are also leading to a more long-term higher relative learning retention related to learning general knowledge of Engineering Thermodynamics. However, it should be noted that a significant difference regarding relative learning retention was not identified regarding knowledge and skills required to solve simple or difficult Engineering Thermodynamic problems.

Not surprisingly, no significant learning retention took place between Post-test2 and Post-test1 since students were not exposed to learning Engineering Thermodynamics during this period.

Table 8. Results for 'relative retention' for group (A) versus group (B) (bracket value means result goes against the hypothesis)

Using Post-test2 and the Pre-test results					
Variable	d	df	t-value	Crit. $t_{0.90}$	p-value
J.1	0.02	71	0.07	1.29	0.472
J.2	0.57	71	2.42	1.29	0.009
J.3	0.07	71	0.03	1.29	0.488
J.4	0.11	71	0.48	1.29	0.317
Using Post-test2 and Post-test1 results					
J.1	0.04	71	0.17	1.29	0.434
J.2	0.08	71	0.33	1.29	0.371
J.3	(0.03)	71	0.12	1.29	0.453
J.4	(0.02)	71	0.07	1.29	0.471

To test $H_{0,3c}$ and using the absolute results for Post-test2 (Table 4), it was found that the scores of J.2 and J.4 are significantly larger for group (A) than for group (B), but the scores of J.1 were significantly larger for group (B) than for group (A) (Table 9).

These results show that the absolute learning retention relate to general knowledge of Engineering Thermodynamics and knowledge and skills required to solve difficult Engineering Thermodynamic problems is higher when using constructivist principles. This confirms the earlier interpretation of the results related to $H_{0,1}$ which were based on the difference between Post-test1 and Pre-test scores. However, confirming the previous interpretation of results related to the absolute Post-test1 scores, a traditional learning approach leads to an absolute higher interest in Engineering Thermodynamics.

Table 9. Results for 'absolute retention' for group (A) versus group (B). (bracket value means result goes against the hypothesis)

Using Post-test2 results					
Variable	d	df	t-value	Crit. $t_{0.90}$	p-value
J.1	(0.44)	71	1.91	1.29	0.030
J.2	0.81	71	3.79	1.29	0.000
J.3	(0.25)	71	1.06	1.29	0.146
J.4	0.56	71	1.35	1.29	0.090

Regarding limitations the following can be said. Construct validity of the experiment was ensured by minimizing all influential factors except the different learning approaches. Repeating the same tasks and questions for pre- and post-tests led to a familiarization and maturation effect for the students, but it did not limit experimental validity since it applied to the experimental and the control group. Different levels of motivation or feelings were not observed. The external validity of the findings is given for the perspectives of respondents and scope of this study. Respondents from different socio-economic contexts or a different course content may lead to different results

CONCLUSIONS

Starting with an exposition of common challenges related to learning Engineering Thermodynamics, this study used an experimental approach, including a group of students learning based on constructivist principles, and a control group of students learning based on traditional principles. It was found that students' personal interest in Engineering Thermodynamics is more effectively increased (i.e. relative learning performance) when using constructivist principles, although the traditional approach led to a larger absolute interest when finishing the course, as well as a larger absolute interest four weeks after finishing the course.

All measures related to learning experiences confirm that students learn general understanding of Engineering Thermodynamics more effectively when using constructivist principles. Interestingly, no significant differences between the learning effectivity of the two learning approaches were found regarding students' learning of knowledge and skills that are required to solve *simple* Engineering Thermodynamic problems. Finally, regarding students' learning of knowledge and skills required to solve *difficult* Engineering Thermodynamic problems, constructivist principles led to higher learning effectiveness when considering the relative learning effectiveness within groups (Post-test1 – Pre-test), absolute learning effectiveness when finishing the course, and the absolute retention four weeks after finishing the course. Traditional learning approaches led merely to a significant relative learning (Post-test1 – Pre-test). The findings confirm earlier findings related to active learning in Mathematics for engineering students and leading to better results (Cabo & Klaassen, 2018), and it should encourage engineering educators to incorporate constructivist principles to enhance active learning (CDIO Standard 8) in order to contribute to more sustainable learning of Engineering Thermodynamics.

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