VOL II

Educação:

Teorias, Métodos e Perspectivas

Paula Arcoverde Cavalcanti
(Organizadora)

EDITORA
ARTEMIS
2021

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APRESENTAÇÃO

O Livro **“Educação: Teorias, Métodos e Perspectivas”** é composto de trabalhos que possibilitam uma visão de fenômenos educacionais que abarcam questões relacionadas às teorias, aos métodos, às práticas, à formação docente e de profissionais de diversas áreas do conhecimento, bem como, perspectivas que possibilitam ao leitor um elevado nível de análise.

Sabemos que as teorias e os métodos que fundamentam o processo educativo não são neutros. A educação, enquanto ação política, tem um corpo de conhecimentos e, o processo formativo dependerá da posição assumida, podendo ser includente ou excludente.

Nesse sentido, o atual contexto – econômico, social, político – aponta para a necessidade de pensarmos cada vez mais sobre a educação a partir de perspectivas teóricas e metodológicas que apontem para caminhos com dimensões e proposições alternativas e includentes.

O Volume II apresenta diversas análises acerca de métodos, práticas pedagógicas e educativas. Nele se destaca a ideia dos sujeitos que constroem seu próprio conhecimento, relacionando a teoria à prática e, possibilitando novas perspectivas educativas dentro de realidades diversas.

A educação, entendida como um processo amplo que envolve várias dimensões, precisa ser (re)pensada, (re)analisada, (re)dimensionada, (re) direcionada.

Espero que façam uma boa leitura!

Paula Arcoverde Cavalcanti

SUMÁRIO

CAPÍTULO 14

MEANINGFUL LEARNING IN ENGINEERING: A CASE STUDY IN VOLUMETRIC PROPERTIES OF FLUIDS

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Natalia Muñoz-Rujas
Escuela Politécnica Superior
Universidad de Burgos, España
https://orcid.org/0000-0003-2185-1392

Fatima Ezzahrae M'Hamdi Alaoui
Ecole Nationale des Sciences Appliquées
Université Chouaib Doukkali, El Jadida, Maroc
https://orcid.org/0000-0001-7443-6796

María Jesús González Fernández
Escuela Politécnica Superior
Universidad de Burgos, España
https://orcid.org/0000-0002-2960-5519

Jesús Ángel Meneses Villagrá
Facultad de Educación
Universidad de Burgos, España
https://orcid.org/0000-0003-4839-0418

Eduardo Atanasio Montero García
Escuela Politécnica Superior
Universidad de Burgos, España
https://orcid.org/0000-0001-9948-3767

ABSTRACT: This work presents a case study of meaningful learning in thermodynamics laboratory activities in engineering degrees. Experimental work deals with the determination of the volumetric properties of fluids, and more specifically on the liquid-vapour phase transition. The assessment of the impact of the meaningful learning approach has been carried out through pre-test and post-test knowledge and comprehension questionnaires on a total of 285 students in the 2016/2017, 2017/18 and 2018/19 academic years. The results indicate a substantial improvement in learning new concepts about the liquid-vapour behaviour of fluids, as well as the destruction of misconceptions about the same phenomenon.

KEYWORDS: Meaningful learning. Thermodynamics. Volumetric properties.Engineering.

APRENDIZAJE SIGNIFICATIVO EN INGENIERÍA: UN CASO DE ESTUDIO EN PROPIEDADES VOLUMÉTRICAS DE FLUIDOS

RESUMEN: En este trabajo se presenta un caso de estudio de aprendizaje significativo en las actividades de laboratorio de Termodinámica en titulaciones de ingeniería. El trabajo experimental versa sobre la determinación de las propiedades volumétricas de los fluidos, y más concretamente sobre la transición de fase líquido-vapor. Se ha realizado una evaluación del impacto del planteamiento de aprendizaje significativo mediante cuestionarios ex-ante y ex-post de conocimiento y comprensión sobre un total de 285 estudiantes en los cursos académicos 2016/2017, 2017/18 y 2018/19. Los resultados indican una mejora sustancial en el aprendizaje de nuevos conceptos sobre el comportamiento líquido-vapor de los fluidos, así como la destrucción de preconcepciones erróneas sobre el mismo fenómeno.

PALABRAS CLAVE: Aprendizaje significativo. Termodinámica. Propiedades volumétricas. Ingeniería.

1 INTRODUCTION

Engineering training means nowadays a multidisciplinary approach concerning the high-level skills addressed to labour market and social challenges. This fact motivates higher education's institutions to renovate the education of their graduates. Their training now includes not only the acquisition of technical knowledge, but also thinking and other skill sets such as communication, team-working, etc. (MOHD-YUSOF et al., 2018). The new pedagogies required in current training processes demand changes in relationships between teachers and students, in teaching and learning strategies, and how the learning process is evaluated (MARTÍNEZ et al., 2016). Meaningful learning plays frequently a central role in this new challenge as it refers to the idea that a learned knowledge or fact is fully understood by an individual who can then use it to make connections with other previously known knowledge (VERGARA et al., 2019). Engineering faculty are currently developing pedagogical research in active and meaningful learning in broad variety of engineering disciplines such as drawing, chemical engineering, industrial management, renewable energies, computing, electrical or materials engineering (FERNANDES et al., 2014; HERNÁIZ-PÉREZ et al., 2021; MARTÍNEZ et al., 2016; MAYASARI et al., 2019; RÜÜTMAN, 2020; VERGARA et al., 2019).

Instead of talking about teaching methods, more emphasis is placed on learning strategies, which is more in line with alternative approaches to common traditional methods, the planning of which should necessarily lead to meaningful student learning. Constructivist alternative approaches oriented to conceptual change (DRIVER and OLDHAM, 1986; DUSHL, 1995) or conceptual and methodological change (GIL, 1986; DUSCHL and GITOMER, 1991) dismiss models of transmission learning and mechanical learning as the only ways to acquire knowledge, since they do not establish the relevant concepts (AUSUBEL et al., 1983) suitable for learning (DRIVER, 1988) nor is it sufficiently enhanced the procedural capacities necessary for professional performance.

A learning strategy is a conscious and intentional decision-making process designed to achieve a learning goal. In this strategy the student chooses and recovers the knowledge he needs to complete an objective, depending on the characteristics of the educational situation in which the action occurs (MONEREO et al., 2000). It requires taking decisions in the planning, execution and evaluation of the plan, which in turn implies a continuous review and self-assessment of the learning process.

Laboratory activities are learning spaces where the student develops and acquires practical and intellectual skills that allow him to establish engineering criteria, check and understand the theoretical concepts that he must learn, and above all, establish relationships with other previous knowledge that he already possesses. Given their application orientation we relate them directly to the "know-how" of constructivist models oriented to problem solving with learning by research approaches (GIL, 1993; GIL et al., 1998; CAÑAL and PORLAN, 1997), and with Ausubel's vision of meaningful learning (AUSUBEL, 2003, MOREIRA and MASINI, 2001), which involves understanding, organizing new knowledge and those possessed by the student (accommodation process), and finally a hierarchy of them that allows them to be interrelated to produce the purported assimilation effect.

Therefore, we propose that laboratory practices should be considered as meaningful learning strategies in which the student "learns to think" by solving real problem situations (CANDIDO MAGALHAES et al., 2020). This breaks with the paradigm of classical education focused on the teacher and traditional methods of memorize learning, and aware the student of his or her need to learn to learn, so that with the proper motivation and collaboration of the teacher, he or she can become autonomous for their own learning.

At the University of Burgos, we have used the approach of learning by investigation by Gil (GIL, 1993) to teach the laboratory activities in Engineering Thermodynamics. The central idea is the treatment of open-ended problems, , of interest to students, through which they build their knowledge based on the initial ideas they have and the development of general and specific procedural capacities addressed to the scientific and technological domain (SAIZ et al., 2012). In this teaching methodology, students act "as novel researchers" and conduct research already known by the teacher who performs the dual role of "director" and facilitator of learning (MONTERO and GONZALEZ, 2009).

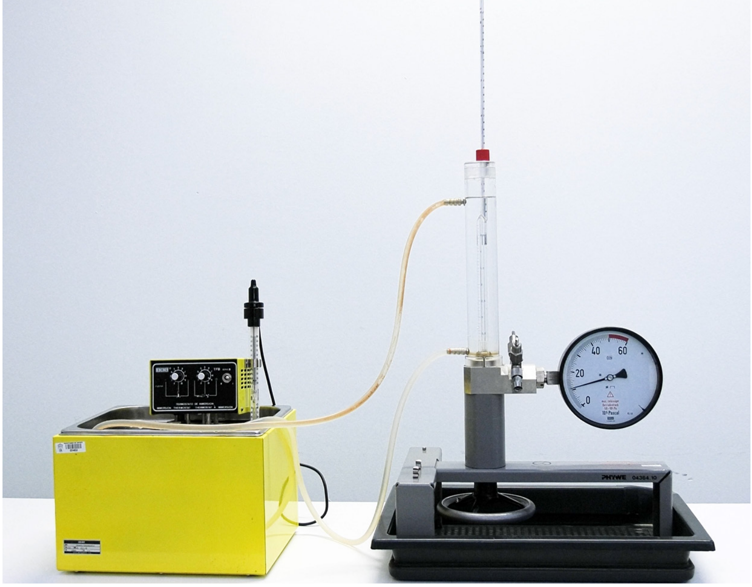
In this contribution we describe the learning sequence used in the activity of a laboratory work on thermodynamic properties of fluids, which we have carried out with 285 engineering students from 2016 to 2019, and the progress made in its meaningful learning, evaluated through an *ad hoc* test.

2 THE VOLUMETRIC BEHAVIOUR OF A FLUID AND THE LEARNING OBJECTIVES

At the Engineering Thermodynamics laboratory we have a test bench provided by the company Phywe Systeme GbmH, which allows the experimental determination of the pressure – volume – temperature (PVT) behaviour of a pure substance, in particular the experimental determination of the critical point of the substance and the measurement of the vapour-pressure curve. The equipment can be filled with several substances, which must have their critical point at a pressure of less than $50{\cdot}10^5$ Pa and at a temperature below 55°C, which are the safety limits recommended by the manufacturer. In the case described below, the fluid sulphur hexafluoride, SF_6, has been used, which presents its critical point at approximately $38{\cdot}10^5$ Pa and 45°C. The vessel containing the fluid under test is transparent, as shown in Figure 1, allowing visual observation of the liquid-vapour transition.

The experimental laboratory device is composed by a graduated tube that contains the transparent fluid with which the experiment will be conducted. The volume of the gas contained in the tube can be controlled by moving a mercury column upwards by operating on a rotating wheel. Then, the volume can be measured in the graduated column. The pressure of the fluid is measured by means of a manometer located in the bracket of the device.

Figure 1. Experimental test bench for the study of the volumetric behaviour of a substance



The spin of the wheel makes the volume change, then changing the pressure. The temperature of the fluid is measured indirectly. The tube that contains the fluid is surrounded by another concentric tube. The annular space is filled with water coming of a thermostatic bath. When steady equilibrium between the studied fluid and the water is reached, both temperatures of the fluids are the same. Then, it is only necessary to measure the temperature in the water. It is critical to keep pressure, volume and temperature values stable in time, while measurements are taken. This state in which properties remain stable in time is the so-called steady state. Usually one of the fixed variables (e.g. temperature) is maintained constant, while looking at the relationship between the other two (volume and pressure).

The student's scientific learning that we intend to build with this equipment are:

i. To determine the mutual dependence of (PVT) properties of the fluid contained in a variable volume vessel by modifying pressure and temperature
ii. To distinguish experimentally the properties of a pure substance in the different operating areas.
iii. To obtain the (P-T) vaporization curve and the (P-V) diagram of a pure substance.

This practical work serves to build in the student the concept of equation of state and to visually correlate the meaning of the terminology typical of the change of liquid-vapour phase (saturated vapour, saturated liquid, overheated vapour, subcooled liquid, critical point, etc.) with the description commonly contained in the Engineering Thermodynamics textbooks.

3 LEARNING THE PRESSURE – VOLUME – TEMPERATURE BEHAVIOUR

Initially, this equipment has been used in the teaching of fundamentals of Engineering Thermodynamics courses of some engineering degrees, such as Mechanical Engineering and Electronics Engineering. The approach was a traditional one, it is to say, the students were given a document with the step-by-step instructions on how to proceed, and then they record data and write the corresponding report. In terms of student's learning outcomes, the observed results in several courses prior to 2012 can be summarized in the following:

1. The reports of this practice were limited to the transcription of the data table provided by the teacher once completed, its corresponding diagram (P-V), and a few brief descriptive paragraphs of the method and conclusions, many of them copied from textbooks and, more recently, internet web addresses-
2. In classroom lectures after the laboratory session, however, it was necessary to re-reproduce graphically the three-dimensional graphs (P-V-T) and their projections, (P-V) and (P-T), with indication of the specific nomenclature

(superheated vapour, saturated vapour, etc.), given the delay with the respective session at the laboratory. Consequently, it was doubtful that the realization of experimental practice would achieve the intended learning objectives.

Considering the contributions of research in the teaching of science and technology, and the accumulated experience of teaching prior to 2012, a new approach to learning is adopted in the use of experimental equipment described in section 2. In this new approach learning is conceived as a conceptual, methodological and attitude change (GIL, 1993). In our case study these changes are:

A. *Learning should consider the student's prior knowledge*. We seek to make the students aware of their previous ideas about the scientific topics being addressed. On the liquid-vapour behaviour of substances, the teacher provokes a debate through questions such as: In what temperature and pressure ranges does the liquid-vapour transition occur? Does this transition occur continuously?
B. *Learning should pose a new situation that causes the student a conflict with his or her previous ideas* and forces him or her to rethink them by analysing data or evidence (proposing hypotheses, drawing conclusions), without reading facts reported by others in books or by the opinion of the teacher's authority: How do I analyse the behaviour of physical properties through their numerical assessment? What hypothesis can I formulate in the light of the data? How do I use my scientific knowledge to draw conclusions?
C. *Learning must be meaningful in responding to problems and being placed in a context of interest beyond purely academic*. In this case, being an engineering degree, learning should be placed in a problem context of industrial interest. For this purpose, there are questions that arise the curiosity and interest of the student. In the laboratory practice we posed questions such as: Why is it necessary to know this information about substances? How do industrial fluid suppliers and the engineers that design fluid facilities make use of this information?

From this starting point, a new way of conducting the learning session, based on the model of learning as research, is proposed, although the same learning objectives are maintained (the technical objectives which the apparatus allows to obtain):

A. *To raise contextualized problematic situations of interest*. A fluid manufacturing chemical company has synthesized a new fluid and must obtain its (PVT) behaviour to include it in the product's technical brochure.

This information is needed by design engineers to size their equipment (pipes, tanks, pumps or compressors, if any, etc.). The session takes place in a 4-hour time limit, there is not as much time as you want. The session is conducted in the lab with the entire group of engineers simultaneously. Learning new scientific concepts over the experimental skills of young engineers (students) is prioritized.

B. *The roles of the teacher and the student*. The session is raised as if the students were newly graduated and newly hired engineers in the company. The teacher has the role of the production engineer, as tutor of the new young engineers. He or her has to guide their learning and performance, but the work must be theirs.

C. *Students' previous knowledge*. The responsible engineer (teacher) expects heterogeneity in the previous knowledge of his young engineers, due to the diversity of previous training (baccalaureates, vocational training, etc.), eventual professional experience of some of them (family business, summer jobs, etc.), different predisposition towards fluid physics, etc. In order to know the starting point of the training, and before starting the work, the teacher proposes a previous knowledge test.

D. *Empirical evidence and hypothesis formulation*. As a result of the analysis of the contextualized problem proposed, students formulate hypotheses based on their previous knowledge. The introduction of new concepts by the teacher helps the interpretation of the data and the students to reformulate their ideas, emerging new hypotheses and problems. The responsible engineer (teacher) leads the learning through questions rather than statements and monitors the safety of the experimental session. The young engineer (student) must formulate hypotheses and submit them to critical discussion of others. The responsible engineer (teacher) has this session well prepared to lead meaningful questions about the learning required for the performance of a young engineer (student) in the company.

E. *The drawing of conclusions*. Final obtaining of (PVT) data table and (P-V) and (P-T) diagrams. Definition of all points and significant areas of the diagrams. Extrapolation of these concepts to the generality of fluids. Strengthening the context of industrial interest by declaring the actual industrial uses of the fluid used (sulphur hexafluoride, for example). Elaboration of a conceptual map with the concepts worked.

F. *Checking the evolution of students' knowledge*. In order to know the improvement of learning, and after the end of the session, the responsible engineer (teacher) proposes as a final test the same previous knowledge test. Both are evaluated and delivered to the young engineer (student), so he or she can compare both results and check the conceptual changes on the initial ideas.

4 RESULTS AND DISCUSSION

During the academic years 2016/2017, 2017/18 and 2018/19 this methodology was applied to a set of 285 students of Engineering Thermodynamics, coming from the Electronics Engineering and the Industrial Management Engineering curricula. Students were clearly indicated that the results of the evaluation of this session had no impact on the qualification of the subject, with the aim of avoiding random responses. Table 1 presents the set of 10 questions with alternative answer that has been used in both the pre-test and the follow-up post-test used.

Table 1. Questionnaire on the volumetric behaviour of a pure substance

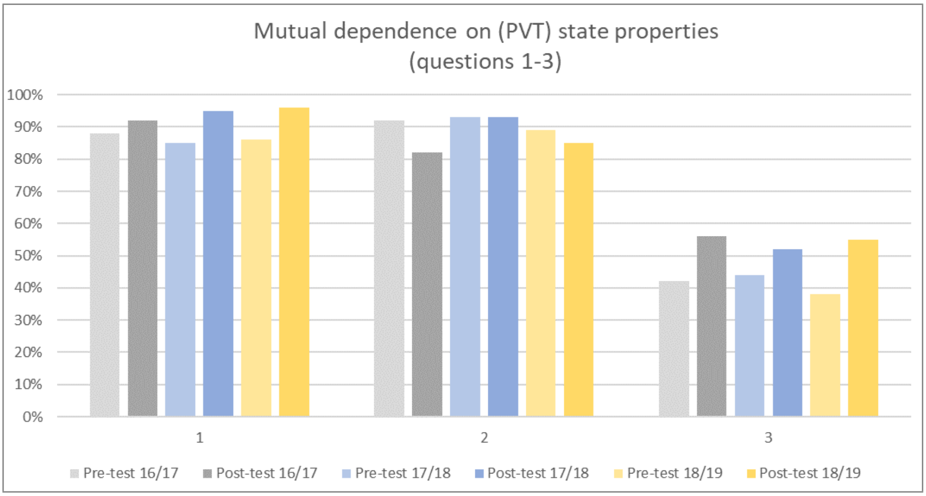
Item	Question
1	When compressing a gas at constant temperature, the volume a) increases b) decreases c) keeps constant
2	When compressing a gas at constant temperature, the pressure a) increases in the whole interval b) decreases in the whole interval c) keeps constant in the whole interval
3	When reducing, in the same amount, the volume of a gas and those of a liquid a) the pressure of the gas increases much more that the one of the liquid b) the pressure of the liquid increases much more that the one of the gas c) pressures increase equally both in the gas and the liquid
4	For a pure substance at constant temperature, the saturation pressure along the phase change from liquid to vapour (gas) a) increases b) decreases c) keeps constant
5	The difference in density between the liquid and the vapour (gas) phases along the vaporization at constant pressure a) increases when pressure increases b) decreases when pressure increases c) is independent of pressure
6	For any pure substance, the phase transition from liquid to vapour (gas) state done at constant pressure, it takes place also a) at constant volume b) at constant density c) at constant temperature
7	For any pure substance, the boiling temperature a) is a constant b) is 100°C c) depends on the pressure
8	For a pure substance, we can distinguish between liquid and vapour (gas) phase a) at any pressure b) at pressures under the critical pressure c) at pressures over the critical pressure
9	The state of a fluid in which, within the gas phase, the first drop of condensed liquid appears, is called a) saturated liquid b) saturated vapour c) saturated solution.
10	The condition for the coexistence of solid, liquid and vapour phases in a pure substance is referred to as a) melting point b) critical point c) triple point.

The 10 questions were raised in a manner consistent with learning objectives: (i) determining mutual dependence on (PVT) state properties for the fluid contained in a variable volume device by modifying pressure and temperature (questions 1-3); (ii) experimentally distinguish the properties of a pure substance in the different operating areas (questions 4-7); (iii) obtain the vaporization curve (P-T) and diagram (P-V) of a pure substance (questions 8-10).

Figures 2 to 4 present for each question, both for pre-test and post-test, and the percentage of successful answer. In general, it is observed that the most of post-test results contain a higher success rate than pre-test.

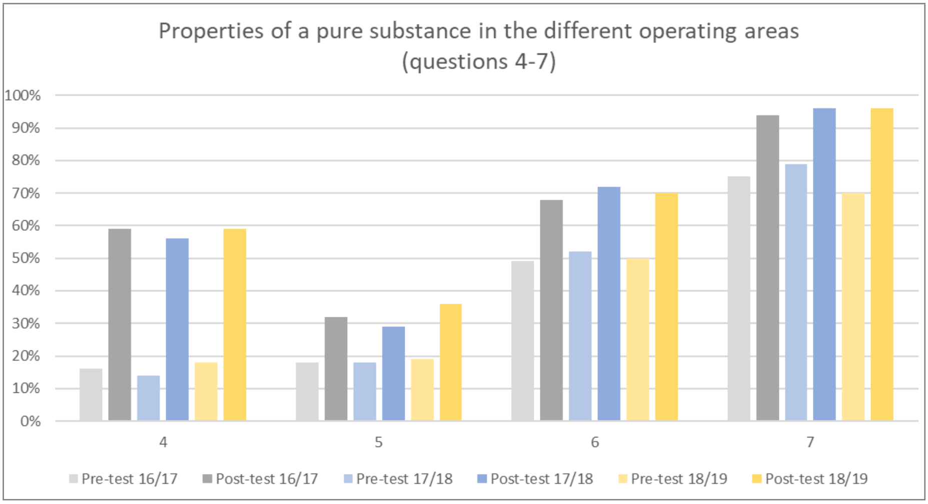
In figure 3, questions 1 and 2 about the behaviour of a gas reflected the best initial knowledge of a gas's behaviour, most likely because it is the most repeated knowledge in high school physics courses (score over 80%). There is a unique fact here, which is that question 2 shows a slight decrease in the right answers after the training session in the 2016/17 and 2018/19 series. Following individualized tutoring with students, this change is primarily attributed to the phrase "in the whole the interval", which some students extended to all fluid behaviour, although the question is clearly limited to gas. Question 3 on the different compressibility of liquids and gases, while improving from pre-test to post-test in success, still leaves an average of 46% of failed responses, indicating the need to delve into this type of behaviour, perhaps in a subsequent working session. Compressibility is also likely to be a more complex property than other introduced in this session, as it must be numerically elaborated from (PVT) direct experimental data and is not obvious.

Figure 2. Questions 1-3, mutual dependence on (PVT) state properties for the fluid.



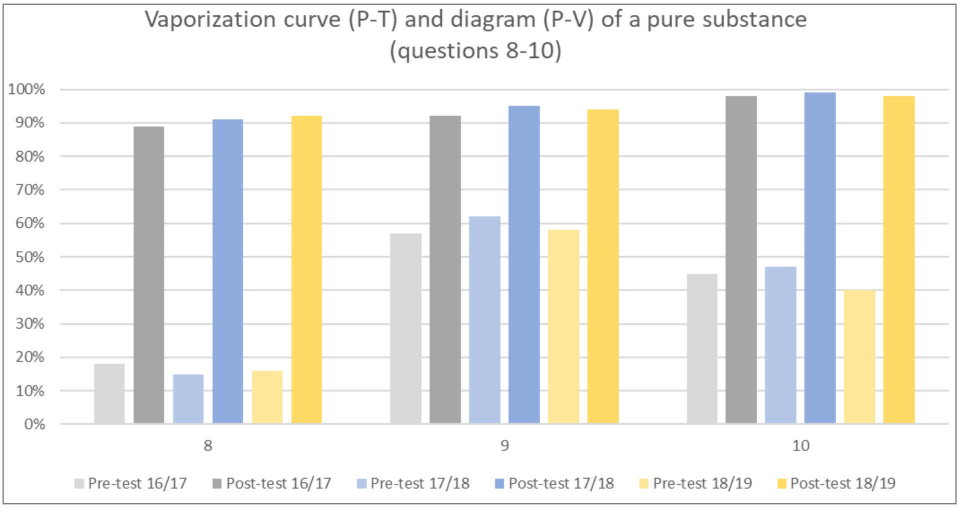
With regards to the fluid behaviour in the vapour-liquid area (Figure 3, questions 4 to 7), the most substantial improvement of 42% in average occurs in question 4 on pressure-temperature correlation during the phase change. The other questions 5 to 7 present similar improvements in right answers (14% to 21%). It is clear that the concept of the difference in density between liquid and saturated vapour during the coexistence of the two phases is the most difficult concept to learn (question 5, 32% success in average) and that it will require more work on subsequent exercises through the thermodynamic properties of density-like behaviour, such as specific volume, enthalpy or entropy. It is also significant that the pre-test reflects only an average of 75% success in that the boiling temperature depends on the pressure (question 7), although the success rate is 95% in the post-test.

Figure 3. Questions 4-7, properties of a pure substance in the different operating areas.



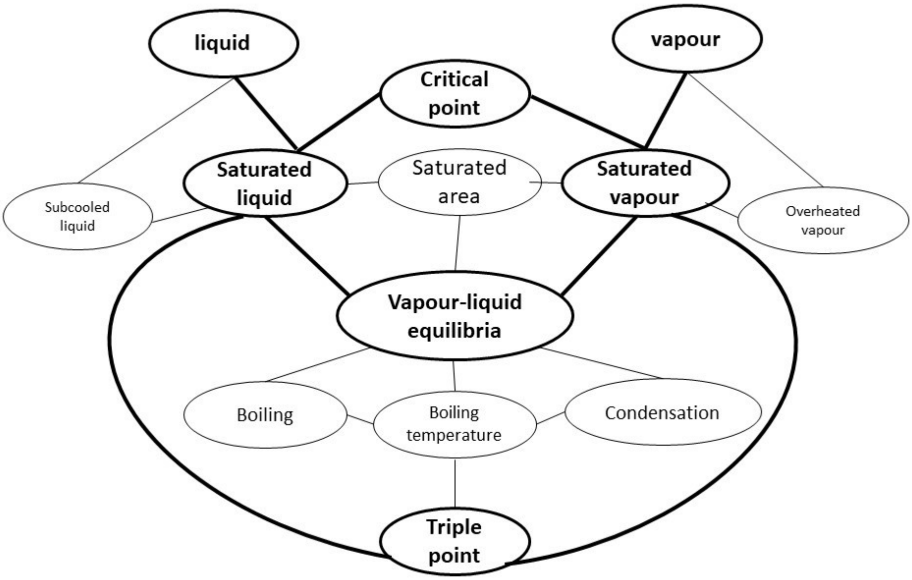
Regarding the overall PVT behaviour of fluids through their visualization in (P-V) and (P-T) diagrams (Figure 4), it can be observed that it is in these concepts where the most significant changes occur in the student learning. It means the new concepts of the limited (P-T) area for the liquid-vapour transitions (question 8, increase of 74% in right answers), and the definition of the critical point and triple point (question 10, increase of 54%). It can be said that this part of the session has resulted in the rupture of some erroneous preconceptions (boiling and condensation throughout the P and T range) and the emergence of new states of fluids. The range of correct answers in the post-test results within this set of questions 8 to 10 are the largest in the entire survey (89% to 98%).

Figure 4. Questions 8-10, vaporization curve (P-T) and diagram (P-V) of a pure substance.



In addition, a conceptual map on the concepts worked in the session was developed. This work came after global discussion in each session, moderated by the teacher. As an example, Figure 5 shows the final form that was reached after the discussion was completed in one of the sessions.

Figure 5. Conceptual map developed by the students.



The uniqueness of the liquid-vapour transition zone, bounded by the borders of liquid and saturated vapour, is noted prominently. The upper limit where both saturation lines converge (critical point), and the lower bound, the triple point line, are the student's main new conceptions. The students use these new concepts as the frame for their usual prior knowledge, such as boiling and condensation processes or the traditional distinction between liquid and vapour, now with more precise denominations (subcooled liquid, overheated vapour).

5 CONCLUSIONS

This work presents a meaningful learning experience in an experimental volumetric fluid behaviour session in the teaching of Engineering Thermodynamics. A case study is presented with expression of the results of variation in the learning of thermodynamic concepts of the liquid-vapour behaviour of pure substances, using the pre-test and post-test method. The results indicate a meaningful improvement in learning, when the experimental session poses a contextualized and interesting problematic situation for students, where they must express their ideas through the formulation of hypotheses and the establishment of conclusions, the result of the observation and analysis of the data and evidence obtained. Given the limited time usually available for experimental practice, the situation was not fully open and was guided by the teacher, although it was sought that the formulation of hypotheses, their reformulation as new scientific concepts and the elaboration of conclusions was the task of the students. It has also been observed that this method allows to contest some misconceptions of the students and to firmly settle the new concepts, while enhancing the development of practical skills and abilities. Likewise, the established discussions between the students and the communication of the experimental process followed and their findings, has an impact on the consolidation of the conceptual and procedural knowledge of the students. The experience can be useful for other engineering and science teachers since their methodological basis are easily transferable to other topics.

As final conclusion, we can state that laboratory activities, when adopted active learning strategies, are an effective constructivist type tool that allows students to build knowledge to address problems like those they will face in their professional life. In addition, this methodology develops instrumental and practical skills in them, boosts their autonomy and aim to investigate, and benefits the individual and teamwork ability, which allows the optimization of resources, following the guidelines of the research method.

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SOBRE A ORGANIZADORA

Paula Arcoverde Cavalcanti - Doutora em Educação pela Universidade Estadual de Campinas (UNICAMP). Professora Titular da Universidade do Estado da Bahia (UNEB), atuando na graduação em Licenciatura em Geografia, Licenciatura em Letras e na Pós-Graduação em Geografia e Desenvolvimento Territorial. Integra Grupo de Pesquisa - CNPq - Análise de Políticas de Inovação (GAPI), vinculado ao Departamento de Política Científica e Tecnológica da UNICAMP. Atuou como Coordenadora do Curso de Pedagogia (Campus XIII-UNEB), Coordenadora da Pós-Graduação Mestrado em Cultura, Memoria e Desenvolvimento Regional e Coordenadora do Programa Institucional de Bolsas de Iniciação à Docência (PIBID). Tem atuado profissionalmente na área Gestão Pública, Análise e Avaliação de Políticas Públicas e de Educação. Autora dos livros "Análise de políticas públicas: um estudo do Estado em ação" e "Gestão Estratégica Pública".

ÍNDICE REMISSIVO

EDITORA
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