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E-learning tools and pedagogies for studying STEM

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Abstract: The advancement of information and communication technology (ICT) in the twenty-first century enables students to be more active participants in the learning process. The course in thermodynamics is one of the disciplines whose material content comprises of real theory and practice, as well as the use of formulas. As a result, there is a need for a learning model that can assist students locate and solve issues, as well as explain their findings, in order to achieve the basic competences of the thermodynamics course. This work provides an e-learning-based educational package comprised of three programs: VOLCONTROL, which focuses on the analysis of steady-state flow devices, CarnotCycle, which analyzes reversible and irreversible processes, and CombustionUA, which studies combustion processes. The educational package was created to promote significant learning on some thermodynamic topics in undergraduate students, as well as to assist students in developing cognitive competencies such as interpreting, arguing and proposing, and interacting with various graphical user interfaces to solve relevant case studies. Furthermore, the teaching-learning activity assists learners with comprehending the impact of a certain variable on the energy and entropy behavior of the chosen systems, which is normally studied manually in a classroom. The results of the student's tests revealed that the average grades acquired by the students in the problems utilizing the software were higher than the average grade obtained without using the software.

Keywords: STEM, Thermodynamics; e-learning; educational package; teaching-learning activity

1. Introduction

The advancement of information and communication technology (ICT) has accelerated the rate of information access. The interactions that have transpired have been made easier and more diverse (Drigas A.S., Vreattaros J., et al., 2005). The advancement of ICTs has resulted in the development of new techniques of learning. These innovative strategies can be included into instructional materials. Learning can be displayed contextually (Rahmayanti, 2015). The usage of ICT has significantly altered the 21st century learning process. The formal learning process can now be carried out outside of the classroom using ICT (Zubaidah S., 2016).

ICT integration also improves student-centered learning processes. Students in the twenty-first century must: (1) become accustomed to locating information; (2) be able to identify and define problems; (3) be able to work successfully in groups; and (4) be very creative (Sani RA., 2014). Teachers' role in the learning process is currently shifting to that of a facilitator for pupils. Instructors must be capable of designing learning based on the characteristics of pupils in the twenty-first century. Teachers must blend students' competences with the expectations of 21st century skills when preparing students (Mitsea E., Drigas A. & Skianis C., 2022).

The application of learning requires collaboration between teachers and students. Instructors must be capable of incorporating ICT into the learning process. Instructors must also be proficient in the use of ICT media (Harianto I., et al., 2016). Students must be able to learn and innovate, as well as use technology and information media to work and thrive (Haryono 2017). Pupils must acquire 4C skills (communication, collaboration, critical thinking and problem solving, and creativity and innovation) (Drigas A. & Dourou A., 2013). The use of ICT in learning planning is inextricably linked to the learning model selected in the learning plan. The problem-based learning model is one of the best learning methods for developing students' critical thinking, creative thinking, collaboration skills, and communication abilities (Drigas A.S., Ioannidou R.E., et al., 2014).

One type of ICT application in education is the implementation of the learning process through the use of various electronic learning resources. ICT may make use of the internet network, which is limitless in terms of area and time. The use of ICT in the learning process, as part of a system known as E-Learning (Drigas A. & Koukianakis L., 2004). E-learning is the process of learning via the use of computer and internet technology (Silahuddin, 2015). In addition to technology features, building E-Learning must consider pedagogical factors, as learning is a multifaceted process that includes cognitive, emotional, and psychomotor components (Drigas A.S. & Pappas M., 2015). E-learning designers must also consider the needs of its consumers so that the website built can be used publicly (Papoutsi C., Drigas A. & SKiannis C., 2021). Graphic aspects of the website are equally crucial to consider in order to attract a large number of users (Drigas A & Vrettaros J., 2004).

The technical development of E-Learning is divided into two types: LMS (Learning Management System) and CMS (Content Management System) (Trisnaningsih S., 2016). WordPress is one of the world's most popular content management systems (CMS) (Pappas A.M., Demertzi E., et al., 2019). WordPress has various advantages, including the fact that it is free, open source, easy to use, has a large number of plugins that are always being developed, is SEO friendly, and can be used offline (Drigas A.S., Vrettaros J.,Stavrou L., et al., 2004).

2. Review of the literature

Many research findings in recent years have highlighted the value of e-learning-based education for the development of cognitive skills in undergraduate students (Dominoc M. & Francis S., 2015). Virtual environments can be integrated into practically all subject content generated in any university curriculum, enabling for more effective knowledge transmission and the development of critical and analytical thinking in students (Drigas A.S., Vrettaros J. & Kouremenos D., 2004). E-learning is especially important for students because, in some circumstances, it is impossible to build a learning process without Virtual environments. Furthermore, the connectivity provided by these instruments is a vital component for the growth of the teaching-learning process outside of the classroom. It allows access to information from anywhere (Hurlbut A.R., 2018).

Notwithstanding this reality, few policies and initiatives have been devised to encourage the use of e-learning and educational software in engineering education (Banday M.T., et al., 2014). It could be related to the belief that e-learning and educational software will replace the traditional classroom as a means of understanding for this generation (Drigas A.S. & Kouremenos D., 2005). Nonetheless, certain corporations, educational institutes, and university professor research groups underline the need of developing high-quality content classes based on e-learning for engineering education (Drigas A.S., Vrettaros J. & Kouremenos D., 2005). They also emphasize the building of significant learning environments, which is based on both Constructivism and Cognitivism educational theory (Drigas A., Mitsea E. & Skianis C., 2022).

Significant learning based on practical experiences in e-learning (Pappas M., Demertzi E., et al., 2018) and educational courses (Drigas A. & Koukianakis L., 2006) has been crucial in the learning processes for engineering students since it has permitted complementing the theoretical notions gained in an academic thermodynamics class (Mulop N., et al., 2014). E-learning allows for the development of critical thinking and self-learning through the use of Information and Communication Technologies ICT integrated by developed software (Drigas A.S., Vrettaros J., Koukianakis L.G. & Glentzes J.G., 2005).

The constructivism theory, on the other hand, was established by influential authors such as Jean Piaget and Lev Vygotsky (Demertzi E., Voukelatos N., et al., 2018). It is based on the establishment of very relevant authentic educational activities in the field of specialized knowledge for the construction of new knowledge (Mitseas E. & Drigas A., 2019). Hence, for the development of activities with the support of e-learning, students acquire new knowledge while drawing on past lessons in core concepts and definitions (Kokkalia G.K. & Drigas A.S., 2016). Another essential educational theory in the development of e-learning learning techniques is cognitivism (Kokkalia G., Drigas A.S. & Economou A., 2016), in which students organize their mental schemes to gain the necessary knowledge in the best way possible through interaction with the established instruments. Hence, the usage of educational software increases the development of cognitive capacities in students (Drigas A., Mitsea E. & Skianis C., 2022). Several commercial software solutions and tools, such as ANSYS, ChemCAD, and Hysys, among others, enable the construction of specific studies (Li W.W. et al., 2017). Unfortunately, due to the high technological requirements, these tools have not been frequently used in the learning process of engineering students. Consequently, low-complexity computer solutions based on educational software have been proposed to enable better conceptual adoption of the issues concerned (Drigas A., Mitsea E., et al., 2022). As a result, teaching modules in e-learning platforms have been created to encourage the usage of thermodynamics programs. It was designed for thermodynamic analysis of open systems [58] and the computation of entropy and exergy in closed systems (Biasi M., et al., 2017) to determine the good influence it has on pupils.

3. E- learning technology

Junglas (Junglas P., 2006) use an interactive simulation program based on the classical technique to conduct virtual experiments with the goal of delivering insights into abstract concepts that can lead to better mental models and engaging students in active learning. There were six programs that only dealt with ideal gas laws and gas cycles. Anderson et al (Anderson

E.E., et al., 2005) created an active learning program on CD-ROM. The program offers interactive activities, rapid feedback, graphical modeling, physical world simulation, and exploration. Interaction and exercises include narrative voice-overs and animations, interactive questions, short-response interactions, coaching interactions, and experimental simulations. Many of the screens have cursor-over pop-ups that reveal supplementary images or information about the topic. The module appears to have been created with the constructivist learning paradigm in mind and covers all of the subjects in introductory thermodynamics.

Thermodynamics education courseware (Liu Y., 2009) was created to solve three sorts of fundamental thermodynamics problems: detecting gas status after specified operations, evaluating pure material thermodynamic properties at specific states, and analyzing power, refrigeration, and heat pump cycles. The courseware is incredibly instructional and user friendly for data and information input. The proposed program merely gives basic governing equations for the cycles from the standpoint of the conservation of energy principle. As a result, it does not cover all of the subjects in introductory thermodynamics. Bullen and Russell (Bullen P. & Russell M., 2007) employ a mixed learning approach to teach thermodynamics to first-year engineering students. The strategy includes lecture, tutorial, and laboratory sessions, as well as the use of a managed learning environment (MLE) and other opportunities to increase cooperation and contact between students and between students and staff. This comprises weekly assessed tutorials that are computer-aided to provide students with immediate feedback, peer evaluation of laboratory reports, and just-in-time training. It provides tools to improve teaching and learning by delivering course content and facilitating online discussion, group work, and active learning. The blended learning technique appears to support constructivist learning theory. Others had used cyclepad (Bravou V., Oikonomou D & Drigas A., 2022), an articulate virtual laboratory (AVL) that is user-oriented and serves as a self-learning tool. Students can build, develop, and analyze thermodynamic cycles while receiving mentoring. The software applications make conceptual activities more accessible to pupils and explain the "how" and "why" of the science behind their construction. The software acts as a monitoring tool during the problem-solving process, relieving pupils of the load of repetitive numerical and algebraic calculations. It also shows pupils the formulas that underpin all of the values that it calculates.

A virtual power plant website (Kelly G., 2002) was created to assist undergraduate mechanical engineering students in understanding thermodynamic principles through the investigation and modification of plant operations in a virtual learning environment. Students can use this knowledge to tackle real problems by developing, analyzing, and manipulating the operations of a power plant. The two simulation packages employed are realistic and provide learners with motivation, student-centered activities, and opportunities for reflection and collaborative knowledge development.

Huang and Gramoll (Huang M. & Gramoll K., 2004) created an interactive multimedia online e-Book to help students learn basic principles in engineering thermodynamics. The e-Book is case-based and contains 42 real-world case issues, with each example provided in four parts: introduction, theory, case solution, and simulation. The fourth section allows students to participate in a simulation by adjusting the parameters of the case problem and stimulating their thinking. Videos, graphs, pictures, animations, sounds, and tables are used extensively in the e-Book to assist visualize and demystify abstract thermodynamic concepts such as enthalpy and entropy. The e-Book covers the same subject as a normal undergraduate engineering thermodynamic text book. Cox et al (Cox J., et al., 2003) also employed interactive simulation software, a Physlet-based curricular material developed to help students learn thermodynamic concepts with a special emphasis on the application of kinetic theory models. The minimal animation of Physlet activities allows students to concentrate on the desired concepts. These exercises assist students in visualizing ideal gas particle dynamics and engine cycles, as well as developing a conceptual framework for problem resolution. The software assists students in studying thermodynamics by offering dynamic linkages between graphs and thermodynamic processes, simulating real-world applications, and modifying the characteristics of various systems.

Chaturvedi (Chaturvedi S., 2007) created an alternate web-based interactive learning tool for thermodynamics ideas relating to multi-staging in compressors and turbines alone, and thus does not cover other thermodynamic themes. The system makes use of simulation and visualization tools. The authors stated that providing visual depictions of complex thermodynamic devices and allowing students to relate these images to thermodynamic processes on temperature-entropy diagrams can improve students' learning. "Learning by doing in a virtual world" is the pedagogy adopted. Students calculate the final total cycle efficiency manually using computer produced figures and necessary formulae. This keeps the students engaged in their involvement with the module. Ngo and Lai (Ngo C.C. & Lai F.C., 2003) created an online thermodynamics courseware that provides the concepts in a dynamic and interactive manner. The course module provides thorough notes provided in a visually appealing manner, with the use of interactive simulations, animations, and examples to reinforce concepts in the classroom. Workshops are included in the courseware to help students become familiar with the use of thermodynamics tables. Meanwhile, Kumpaty (KumpatynS.K., 2002) uses expert system for thermodynamics (TESTTM) software in his works to help students master the foundations of thermodynamics. The TESTTM is an interactive test that is used in assignments, design projects, and laboratories. Similarly, Weston (Weston A.J., 2008) created software for visual and interactive thermodynamic cycle models.

Lewis et al (Lewis E.L. et al., 1993) used the computer as Lab Partner (CLP) curriculum to address students' inability to connect thermodynamic concepts to more complex phenomena and to emphasize understanding. It comprises of an 11-week microcomputer-based study of thermodynamic properties and variables, as well as simulations of difficulties experienced in students' daily lives. Students combined real-time data collecting with simulated experiments and then generated predictions and reflections.

4. Case studies

Volcontrol was used to analyze a nozzle.
The behavior of a water vapor nozzle was investigated using the operating settings provided in Table 1 and the effect of temperature change (T1-T2) on the ratio of areas (A2/A1) and the ratio of inlet and exit steam velocities (V2/V1). The output temperature was adjusted every 1 C, while the entrance temperature remained fixed. The outlet pressure was varied every 50 kPa between 100 and 250 kPa. Figure 1 depicts a screenshot of a VOLCONTROL GUI while solving the case study mentioned above for one of the given operating circumstances. Figure 2 demonstrates how the pressure differential affects the velocity of the fluid at the nozzle's exit. This occurs because the enthalpy of water vapor is affected not only by temperature but also by pressure. Also, for the same difference in temperature, the output velocities drop as the pressure difference grows. As the temperature difference is raised, however, this effect is significantly reduced (Acevedo J.G., Ochoa G.V. and Obergon L.G., 2020).

Table 1. Operating conditions of the nozzle.

P1 (MPa)	T1 (_C)	V1 (m/s)	A1 (cm2)	Q_ (kW)
0.3	200	45	110	1.5

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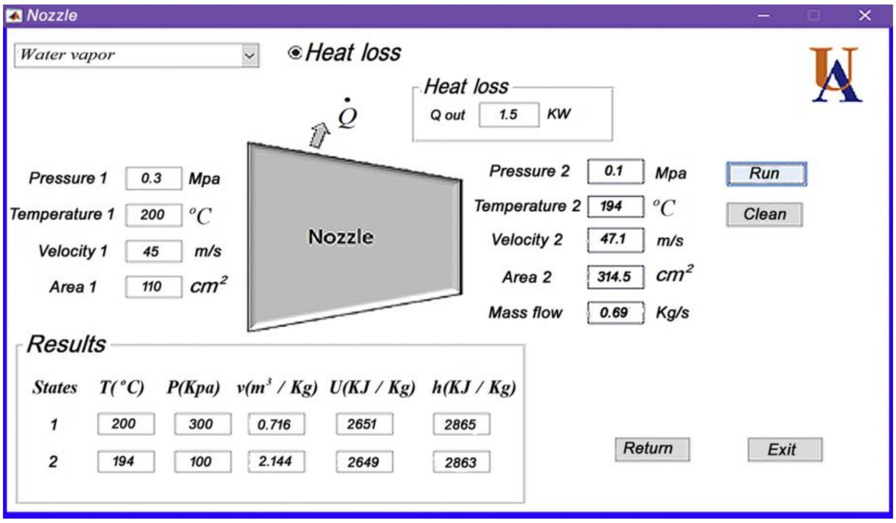

Figure 1. A screenshot of the Volcontrol software's graphical user interface.

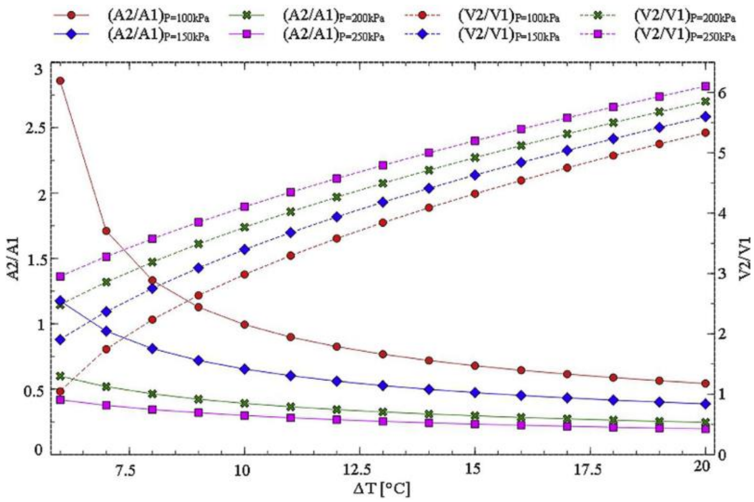

Figure 2. Velocity and area ratios as a function of temperature difference at the output for varied pressure values.

Unusual behavior is noticed when operating with low pressure at the nozzle exit and a modest change in temperature, regardless of the working fluid. Because the A2/A1 ratio is greater than one, the nozzle acts as a diffuser in these situations. When the temperature differential is larger, the nozzle returns to its typical behavior. It indicates that there must be a constraint on the nozzle's operating circumstances at high P and low T to allow the theoretical thermodynamic conclusions to match the nozzle's actual behavior.

CarnotCycle compressor analysis of a refrigeration cycle.

The behavior of an air conditioner compressor was investigated by collecting data on the high temperature (TH), low temperature (TL) reversible COP, real COP, necessary power in the reversible cycle (in Rev), and required power in the real cycle (in). The ratio between the reversible COP and the real COP (COPrev/COP) and the ratio between the required power in the reversible cycle and the power needed in the real cycle (in rev/in) as a function of the difference between the high and low temperatures (TH-TL) on) were then plotted for multiple pressure values, operating under the conditions shown in Table 2 (Acevedo J.G., Ochoa G.V. and Obergon L.G., 2020).

Figure 3 depicts a screenshot of the CarnotCycle interface while completing the above-mentioned case study for one of the supplied operating circumstances. Figure 4 depicts the findings of an investigation performed on an air conditioner system's compressor. It can be shown that when the temperature differential (TH-TL) increases, the ratio COPrev/COP drops while the ratio (in rev/in) climbs linearly. The COPrev/COP ratio grows as the compressor's inlet pressure rises. This effect, however, is diminished when temperature differences are large (THTL). When the inlet pressure is increased, the in rev/in ratio lowers. This effect is less when temperature differences are small (TH-TL).

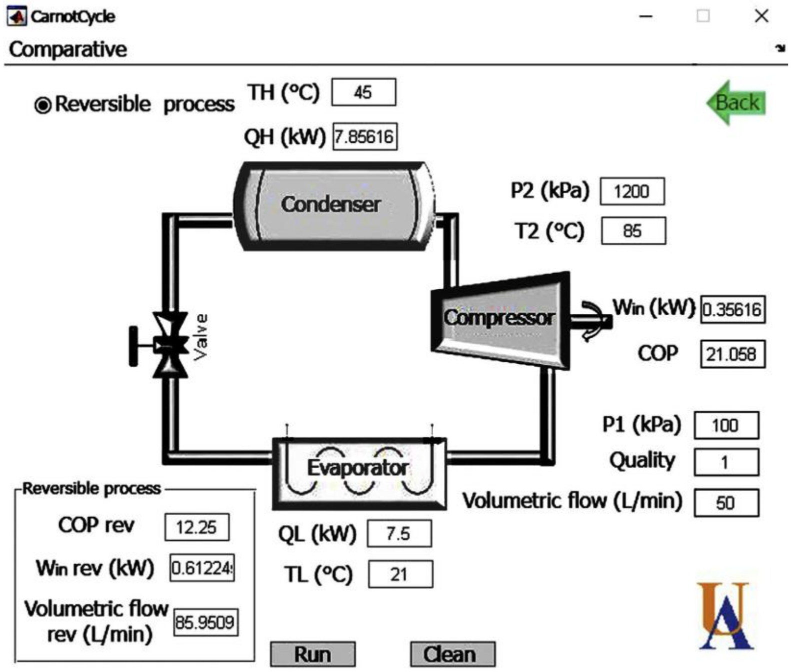

Figure 3. Snapshot of the CarnotCycle software's graphical user interface.

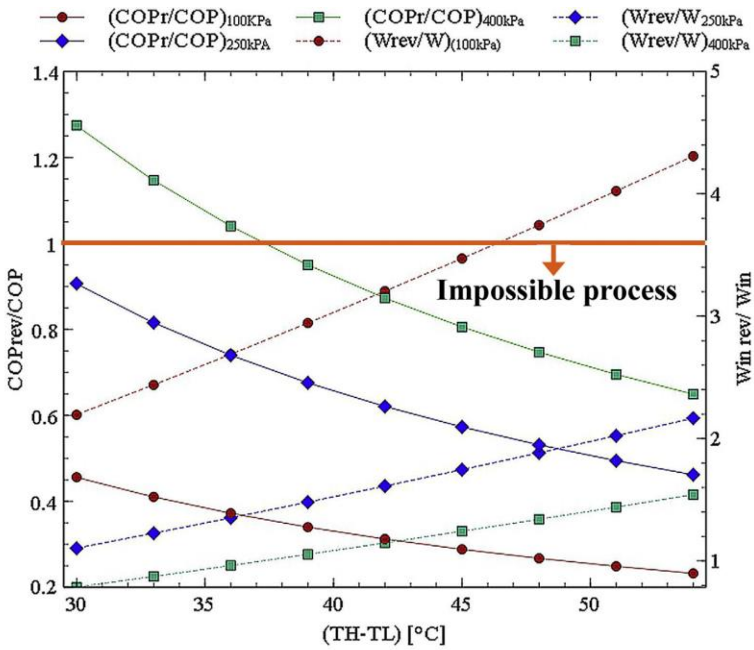

Figure 4. CarnotCycle software was used to analyze the performance of the air conditioner

Table 2. Operating conditions of the refrigeration cycle.

Fluid	V (L/min)	Quality	P2 (kPa)	T2 (°C)	TH (°C)	QL (kW)
R-134A	50	1	1200	85	45	7.5

It is critical to emphasize that findings produced when the COPrev/COP ratio is less than one show that the condition is impossible to obtain. When the COPrev/COP ratio is one, it signifies that the maximum theoretical coefficient of performance was reached. In this case study, it is intended that the student will be able to identify the effect of the source and sink temperatures on the reversibility of the thermal machine. It results in many students acquiring the cognitive talent argumentation claim by witnessing and analyzing an impossible process with COPrev/COP values less than 1 (Acevedo J.G., Ochoa G.V. and Obergon L.G., 2020). The students explain the reason for these seemingly implausible outcomes, concluding that the Clausius statement for the operation of thermal refrigeration machines and heat pumps violates the second rule of thermodynamics in these instances. This case study also achieves the cognitive skill of analyzing data/information (Cognitive Skill - 3, CS3). Ultimately, some students propose novel operating circumstances in which this ratio is greater than one in order to get an irreversible or genuine process.

Excess air analysis in a whole combustion process utilizing CombustionUA.

The behavior of a complete combustion process was investigated to determine the effect of excess air on the adiabatic flame temperature and spray temperature of the products for various fuels operating under inlet conditions of 25 C and 101.325 kPa. Excess air was varied in the range of 0 to 2.25 for three different liquid phase fuels: ethyl alcohol, methyl alcohol, and n-octane. Figure 5 shows a screenshot of the CombustionUA software at the time of solving the case study mentioned above for one of the given operating conditions.

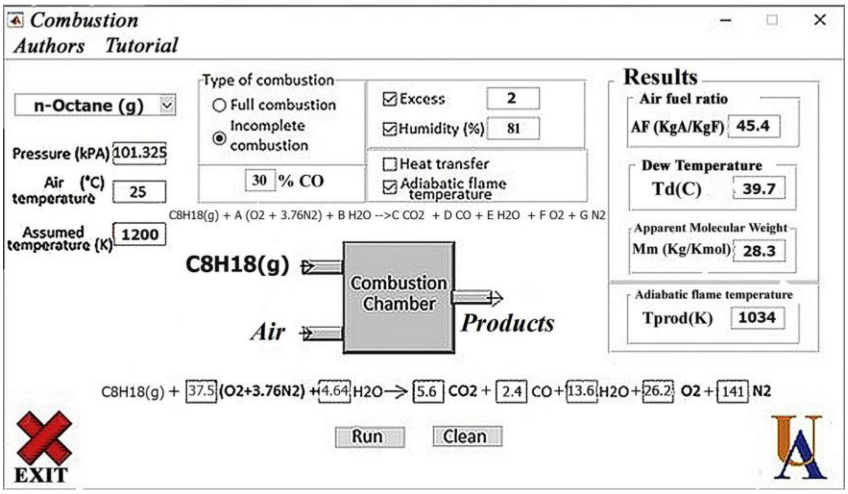

Figure 5. A screenshot of the CombustionUA software's user interface.

Figure 6 depicts the outcomes of a complete combustion process with variable extra air. Because there is no energy loss from the combustion chamber to the surroundings, the temperature of the products is the adiabatic flame temperature. When the surplus air increases, the adiabatic flame temperature decreases dramatically with a parabolic pattern. The dew point temperature behaves similarly to the adiabatic flame temperature in that it has a parabolic pattern and lowers as the extra air increases (Acevedo J.G., Ochoa G.V. and Obergon L.G., 2020). However, the fall in dew point temperature is not as dramatic as that produced with the adiabatic flame temperature.

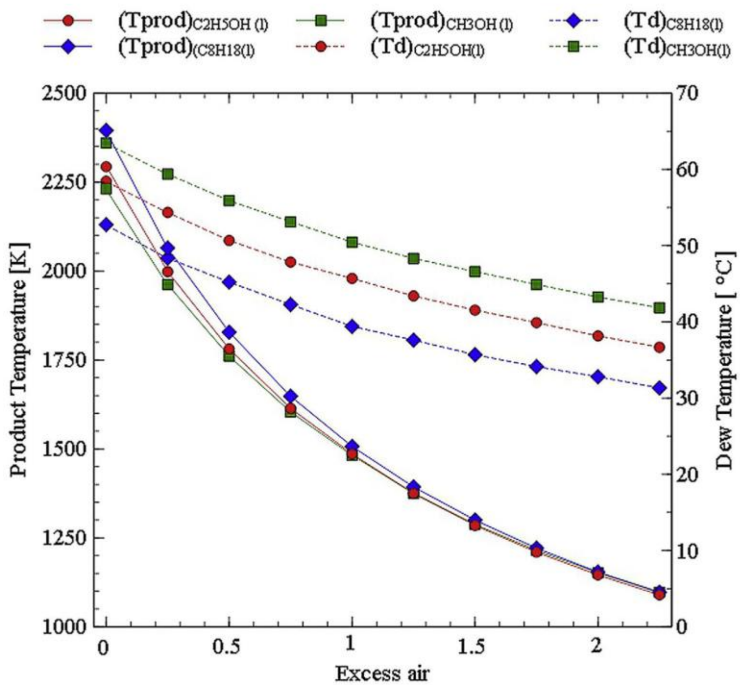

Figure 6. Excess air has an effect on product temperature and dew point temperature in a complete combustion system.

Figure 6 further illustrates that there is no substantial difference in the adiabatic flame temperatures of the examined fuels, which becomes essentially inconsequential as the extra air is raised. However, the kind of fuel has a large effect on the dew point temperature, with methyl alcohol having the greatest dew point temperature and n-octane having the lowest. Based on the findings, it was feasible to identify a number of advantages of the learning methodology described in this work over other alternatives such as blended learning.

Due to the lack of continuous coaching in a classroom, the student's training process demands more work while using e-learning. As a result, the learner learns to take charge of his own training. Furthermore, the integration of the new educational package into the various virtual platforms allows the student to contact the teacher to clarify the concerns of the case studies while also participating in complementary activities such as participation in discussion forums, platform activity, and evaluations. On the other hand, the key advantage noted in this methodology is the flexibility of scheduling, where the student determines when to study and when to download the program. To access the course information, contact the tutors, or take the examinations, the student simply requires an internet connection. At the same time, in the blended mode, this is largely restricted, compromising flexibility with geographical obstacles and required displacements (Acevedo J.G., Ochoa G.V. and Obergon L.G., 2020).

5. Effect of e-learning tools

The lecturer uses passion to invite students to develop an experiment or inquiry of the material being covered in class and in the laboratory. This is seen as a success factor in the deployment of problem-based instructional models based on blended learning, namely students' eagerness to study either alone, in groups, directly, or via e-learning. Students find it easier to find the basic concepts of thermodynamics due to direct investigations and assisted with learning videos that support students' understanding of concepts in every material on the thermodynamics course, according to the researcher's observations.

Laisema and Wannapiroon (2014) concluded that "students' creative thinking skills are effective to enhance with the usage of information technology" in a similar study. Cahyani and Hendrianim (2017) also did research using multimedia and E-learning medium. Cahyani and Hendrianim (2017) discovered that multimedia-based learning can increase student test results. The following is a data presentation to improve pre-service teachers' critical thinking skills on each indicator of critical thinking skills. There are up to five signs of critical thinking that are used: 1) giving a short explanation (elementary clarification), 2) giving a further explanation (in-depth clarification), 3) making a decision or judging (judgment), 4) making conclusions or inferences, and 5) completing strategic activities (strategies).

This research shows that the inclusion of learning videos, extensive explanations in each sub-material, and direct conversation and investigation substantially enhances the growth of many critical thinking signs. Sub material that students can click on to gain more explanation can be viewed more clearly in the following e-learning screen-shoot. Arrows represent submaterial. This image depicts how learning activities using the Problem Based Instruction learning paradigm based on Blended Learning were successful in strengthening students' critical thinking skills.

This success is greatly aided by learning activities that meet a number of active and creative learning criteria: (1) there is innovation in students' critical thinking skills and problem solving abilities, communication and collaboration, creativity and innovation; (2) information, media, and technology skills; and (3) life and career skills (Anazifa & Djukri, 2017; Cetin, 2016;). The outcomes of this study are consistent with Dwijananti and Yulianti's (2010) study, which found that using PBI models in Environmental physics courses can help students in Physics Education study programs build critical thinking abilities.

6. Student Reaction Analysis

The level of acceptance of pre-service instructors to the adoption of the Problem Based Instruction learning paradigm based on Blended Learning in the Thermodynamics course was determined by an analysis of student replies. Students are very satisfied with the use of Problem Based Teaching in conjunction with Blended Learning. The response analysis yielded the following results: The usage of Problem Based Learning models based on Blended Learning has answered one of the questions in this research, which is overcoming the boredom of student learning that arose from the teacher-centered learning center; which in this research switched to student-centered learning. This success is a teaching approach with a suitable structure for physics lectures (Cetin, 2016; Turgut et al., 2016). Consequently, the research objectives were met by the application of Problem Based Learning based on Blended Learning, which has been shown to improve the critical thinking skills of students of Physics education in thermodynamics courses. Furthermore, a review of student responses to this learning revealed that 81% of assessed students were extremely satisfied with this learning paradigm.

This is consistent with the findings of Hakim et al. (2017), who discovered that: 1) Interactive multimedia thermodynamics developed in thermodynamic learning can improve the creative thinking skills of pre-service physics teachers; (2) The highest increase in creative thinking skills occurs in the indicator of flexibility and the lowest in the indicator of originality; and (3) Learning through interactive multimedia thermodynamics is quite effective in increasing the indicator of originality.

7. Conclusion

Many engineering students throughout the world struggle with basic/introductory thermodynamics. This prompted a slew of studies into designing and applying various strategies to improve students' learning of the subject. Many engineering students throughout the world struggle with basic/introductory thermodynamics. This prompted numerous studies on designing and applying various approaches to improve students' thermodynamics learning. To provide interactivity and visualization, the majority of the methods created employ computer technology and multimedia. The strategies increased pupils' performance and skill development. Students provided helpful and supportive thoughts and suggestions. Based on the findings of formative evaluations by media and material experts, it was determined that the E-Learning approach for problem-based learning in the Heat and Thermodynamics material was feasible for students to use. The demands of 21st century learning guide students to learn autonomously. The problem-based learning design presented also encourages students to think critically, create, collaborate, and communicate.

Finally, we must highlight the productive and effective role of all digital technologies in the field of STEM education and pedagogies. These technologies, which include mobile devices (64-73), a variety of ICTs (74-110), AI & STEM ROBOTICS (111-131), and games (132-135), facilitate and improve educational procedures such as assessment, intervention, and instruction. In addition, the use of ICTs in conjunction with theories and models of metacognition, mindfulness, meditation, and emotional intelligence cultivation [136-182], as well as with environmental factors and nutrition [60-63], accelerates and enhances educational practices and outcomes, particularly in STEM education.

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