ENGINEERING DESIGN PROCESS – AN APPROPRIATE PEDAGOGICAL APPROACH FOR TECHNICAL AND VOCATIONAL EDUCATION

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Abstract

Although several researchers have investigated engineering design process (EDP) as an effective pedagogy for technology education in K-12, its potential for technical and vocational education has not obtained much attention. In an ever-changing scientific, technological and social environment, technical and vocational education has not only to provide practical occupational skills, but also to ensure that students will acquire higher order critical thinking, competencies with regard to adaptation, decision-making, creativity and innovation, technological literacy and collaboration skills. This article discusses engineering design process, as an appropriate constructivist approach for contextualized learning and effective connection between theory and practice that fosters the intended learning outcomes for technical and vocational education in the twenty-first century. It is based on an ongoing research project, where we examine, theoretically and practically, how problem solving environments (PSEs) supporting EDP could be developed to underpin effectively engineering design as a constructivist learning activity in the heterogeneous technological classroom, employing activity theory as a conceptual framework.

Keywords: Engineering design process, technical and vocational education, constructivism, teaching and learning methodology, problem solving environments.

1 INTRODUCTION

The adoption of appropriate pedagogic practices is essential for an effective educational provision in the field of vocational education [1]. To address the challenges ensuing from the immense scientific, technological and socio-economic changes, theory and practice in technical and vocational education (TVE) should be learner-centered using motivating learning approaches [2]. More specifically, as it is noted in [2], “experience in the laboratory, workshop and/or enterprises should be linked to mathematical and scientific foundations, and conversely, technical theory, as well as the mathematics and science underlying it, should be illustrated through their practical applications”. New learning constructivist theories raise critical questions about the design of learning environments with regards to “what is taught, how it is taught, and how it is assessed”, to enable them imparting meaningful knowledge to active learners, who will be better prepared to transfer what they have learned to new problems and settings [3]. In addition, Houstis in [4] notes that computers and information technologies (IT) are part of every productive organization of the human enterprise, from manufacturing to entertainment, telecommunications, transportation and education, and they are changing the way we deliver, consume, and administer education.

Traditionally, curricula in secondary vocational engineering education use textbook instruction and hands-on lessons that provide effectively factual and procedural knowledge along with specific technical skills, but often students lack conceptual understanding as an “implicit or explicit understanding of the principles that govern a domain and of the interrelations between units of knowledge in a domain” [5]. New constructivist learning theories emphasize that textbooks and assessment tests promote memorization instead of deep understanding and sense making and suggest that in order to provide conceptual understanding, curricula should be appropriately organized around important ideas or concepts [3].

On the other hand, technical and vocational education provides contextualized learning through practical applications in real-world or simulated contexts [6]. Nevertheless, as Pierce and Jones note in [7], isolated hands-on activities provide a low level of contextualization and problem solving learning, since, “learners may use the tools or materials of a trade, but never experience the higher-level thinking processes required to solve ill-structured problems of the real world”.

In this paper, we explore engineering design, which is a constituent component of the engineering practice, and specifically, the systematic process that engineers employ to define and solve problems, as an appropriate constructivist pedagogical approach for delivering technological knowledge in contemporary high technical and vocational schools. Technological knowledge is distinguished between particular concepts (special to particular technologies such as “electronics”, computer technology, mechanical technology, electrical technology, etc.) and generalities, namely concepts that apply across all technologies, e.g. the concept of systems. Streveler et al. emphasize that many engineering concepts including inner force, stress, strain, electric circuits, heat, temperature, heat transfer, systems and others, are difficult for students to grasp at all levels of engineering education. By providing context to the content, engineering design process (EDP) can be used to introduce abstract and difficult topics to the benefit of both educators and students.

Engineering design has already been employed to support multiple disciplines in the new field of STEM (“science, technology, engineering and mathematics” for K-12 education. Particularly, in the field of secondary technology education, EDP is a well-established tool for providing technological literacy. Changing the name of the International Technology Educators Association (ITEA) to the International Technology and Engineering Educators Association (ITEEA) in 2009, highlights the significant role that EDP holds in technology education. It is also noteworthy, that before the introduction of the American version of engineering design, it had been an established feature of technology education in schools in the United Kingdom.

In this study, we explore the potential of engineering design supported by constructivist learning environments for secondary vocational education following the following actions:

- Examine the consistence of constructivist learning theory with the intended learning outcomes from technical and vocational education.
- Describe the engineering design and argue for the ability of engineering design process to underpin effectively constructivist learning environments.
- Explore the advantages of engineering design process considering the provision of certain knowledge, skills, competencies and attitudes that enable technical and vocational education’s graduates to meet crucial for both workplace and working life demands.
- Enlighten the power of problem solving environments (PSEs) to address the challenges emanating from the implementation of EDP as an effective constructivist instructional strategy in technical and vocational high schools.

2 METHODOLOGY

Section 2.1 comprises a brief overview of technical and vocational education and engineering design. In section 2.2, we discuss the potential of EDP for designing constructivist learning environments in TVE. Section 2.3 describes how engineering design supports technical and vocational education to meet crucial demands in twenty-first century. Finally, in section 2.4 we examine the role of PSEs in the implementation of constructivist learning environments based on EDP.

2.1 Technical and Vocational Education – Engineering Design

2.1.1 Technical and Vocational Education: Initiatives

Technical and vocational education encompasses a variety of content regarding providers and locations, participants, curriculum and outcomes, control and role of the state. This diversity is associated with different historical and cultural contexts not only across countries and regions but also within countries over time. Reflecting the complexity of the field, several titles and acronyms are used to refer to technical and vocational education across the world: Career and technical education, (CTE) in USA; Further education and training (FET) in UK and South Africa; Vocational and technical education and training (TVET) in South-East Asia; Vocational education and training (VET); Vocational and technical education (VTE) in Australia. Currently, TVET is the prevailing term adopted by UNESCO in 2015 to emphasize the holistic view of both dimensions, education and training. Following [2], we use the term “technical and vocational education (TVE)”, as a comprehensive term referring to those aspects of the educational process that involves the study of technologies and related sciences, and the acquisition of practical skills, attitudes, understanding and knowledge relating to occupations in various sectors of economic and social life. This view explains and
emphasizes our focus on vocational education provided in high technical schools (grades 10-12) alongside with upper secondary general education.

2.1.2 Technical and Vocational Education: A Shift from Behaviourism to Constructivism

The behaviourism learning theory has been the prevailing approach in technical and vocational education for over three-quarters of a century [18] and has been questioned by researchers, with regards to the kind of learning it transmits to students ([6], [7], [18]). Traditionally, vocational education has provided its students with a discrete and well-established set of skills and knowledge aiming to prepare them to be able to “do,” to apply knowledge to certain application areas [7]. With the rapid development in occupational, educational, information, and communication technologies, the student's ability to construct viable knowledge and to adapt is paramount [18]. New educational programs should provide not only job skills, but also a solid foundation of usable theoretical knowledge – knowledge that can be retrieved and transferred to various settings and events - higher order thinking, problem solving, and collaboration work skills ([6], [18]). Behaviourism does not adequately address these demands. Instead, they are congruent with a constructive perspective to technical and vocational education ([6], [7], [18]).

2.1.3 A Brief Overview of Engineering Design

Katehi et al. [13] define engineering as “the process of designing the human-made world”. Engineers, using the scientific knowledge, conceive and develop components, systems and processes, such as buildings, roadways, engines, airplanes, computer chips, televisions, manufacturing processes, and assembling procedures. They also design diverse processes ranging from manufacturing processes to assembling procedures.

Engineering design, the process that engineers employ to develop their plans and directions for constructions, is described in different ways in literature. But though several variations of a general design method are applied in practice, an examination of the various design conceptions illustrates that engineers proceed along roughly similar paths when they do their work [14]. Once they define the problem, they search for possible solutions, taking into consideration various constraints including the laws of science, time, cost, available materials, ergonomics, environmental regulations, manufacturability, repairability, safety issues, social factors, and the present state of the art ([13], [14]).

As Katehi et al. [13] explain engineering design is a purposeful, systematic, iterative, creative, based on requirements process, that comprise the following essential components: identifying the problem; specifying requirements of the solution; decomposing the system; generating a solution; testing the solution; sketching and visualizing the solution; modelling and analysing the solution; evaluating alternative solutions as necessary; and optimizing the final design. In order to implement these components engineers, involve three type-specific groups of engineering concepts: science and math concepts, domain-specific concepts, and concepts common to most areas of engineering. Realizing the steps of engineering design process in technical and vocational education entails the alignment with certain attributes of engineering design, described as follows: (1) Analysis, which is a systematic, detailed examination aiming to define or clarify the problem, to inform design decisions, to predict or assess performance, to determine economic feasibility, to evaluate alternative solutions and to investigate failures; (2) Constraints, namely “the physical, economical, legal, political, social, ethical, aesthetic, and time limitations inherent to or imposed upon the design of a solution to a technical problem”; (3) Modelling, defined as any graphical, physical, or mathematical representation of the essential features of a system or process that facilitates both engineering design and the communication of thought processes, insights, and discoveries to others; (4) Trade-Offs are decisions made to resign from or reduce one attribute of a design in order to strengthen another attribute; (5) Optimization that involves the search for the best possible solution to a technical problem in which trade-offs are necessary to balance competing or conflicting constraints; and (6) Systems are organized collections of “discrete elements (e.g., parts, processes, people) designed to work together in interdependent ways to fulfill one or more functions”.

Design can be project or problem-oriented. Problem-oriented approach is used by educators to provide authentic experiences that foster active learning, support knowledge construction, and naturally integrate school learning and real life [19]. Optimization, differentiates engineering design as a pedagogical strategy from the problem solving method [14], and trade-offs differentiates it from scientific inquiry [13]. Nevertheless, scientific inquiry is used by engineers to inform engineering design [13]. Besides, as Grubbs and Strimel [11] report, engineering design process has now replaced
the older concept of technological design since it involves the elements of analysis, modelling and optimization.

Curricula in K-12 interpret the above characteristics, components, and attributes of engineering design through paradigms for designing solutions to problems that include a cyclical pattern of steps expressed in different words and phrases, but based on analogous approaches [13]. A most common conception for EDP in K-12 education is the one proposed by Massachusetts Department of Education’s “Science and Technology/Engineering Curriculum Framework” curriculum guide [14] that include the following steps:

1. Identify the need or problem,
2. Research the need or problem,
3. Develop possible solution(s),
4. Select the best possible solution(s),
5. Construct a prototype,
6. Test and evaluate the solution(s),
7. Communicate the solution(s),
8. Redesign.

2.2 Constructivism and Engineering Design Process in Technical and Vocational Education

The characteristics of design have a paramount impact on subsequent instructional approaches, cognitive requirements from students and expected learning outcomes [11]. The afore mentioned delineation of engineering design entails that it supports a multidisciplinary, contextual, challenging open-ended problem solving instructional strategy, that seems to be ideally congruent with the description given to constructivism learning theory by Briner [20]: “constructivism calls for active participation in problem solving and critical thinking regarding an authentic learning activity that students find relevant and engaging”. It is our intention to explore further the constructivist nature of EDP, by examining its potential to enable the designing of powerful constructivist learning environments in secondary vocational engineering education. Our analysis is based mainly on the work of Bransford et al. [3] with regard to how people learn, taking into consideration the characteristics, constituent components, and attributes of engineering design process.

2.2.1 Constructivist Principles - Constructivist Learning Environments

New, constructivist learning theories, drawing upon rigorous multidisciplinary scientific research, emphasize three core principles regarding how students learn: a) students come to formal education with “pre-existing knowledge”, namely skills, beliefs and concepts that influence their relationship with the learning environment and consequently affect their achieved outcomes. In fact, constructivism assumes that all new knowledge is constructed from previous knowledge, irrespective of the instructional approach. This prior knowledge should be engaged in order to grasp new concepts and information that are taught; b) to develop competence in a field, students must have a rich body of factual knowledge obtained in the context of a conceptual framework and organized in a way that enables retrieval and application; and c) a “metacognitive” approach to instruction can help students to become “active learners”, which means to be capable of defining learning goals and monitoring their progress towards accomplishing them [3].

According to Bransford et al. [3], these constructivist principles lead to four interrelated perspectives of learning environments that optimize learning: (a) Learner-centered environments that take into consideration the strengths, interests, and needs of the learners and provide to teachers the opportunity to elicit prior knowledge, skills and attitudes of students and address their misconceptions; (b) “Knowledge-centered environments that encourage doing with understanding by giving attention to what is taught (information, subject matter), why it is taught (understanding), and what competence or mastery looks like. Knowledge-centered environments intersect with learner-centered environments when instruction begins with a concern for students’ initial preconceptions about the subject matter; (c) Assessment-centered environments emphasize formative assessment – “ongoing assessments designed to make students’ thinking visible to both teachers and students” – in congruence with the learning goals, that facilitate feedback, reflection and revision and help both teachers and students
overly contextualized knowledge is avoided and students can develop abstract representations of knowledge, which can help promote transfer [3]. Finally, by employing engineering design as a model. Furthermore, the same concept can be introduced through different applications. In this way, cross section and stress through scientific inquiry to determine the corresponding mathematical methods form science and mathematics (e.g., students may explore the relationship among force, electronics engineering technicians, to be involved in applying and learning theoretical knowledge (domain specific concepts, laws and principles, technical drawing, science and mathematics) by linking it to practical applications of their interest, within the content of relative workshop lessons. For example, mechanical engineering technicians may design and construct a fastener bolt for a camshaft bearing, while learning the concept of allowable stress in the strength of materials domain. Infusion of challenging problem solving activities, at the proper level of difficulty, not only evokes students’ intrinsic motivation to learn but they are willing to devote more time to learning as well [3]. Engaging in the engineering design process reveals students’ skills, beliefs, attitudes and preconceptions regarding the underlying theory, which as instruction proceeds can be adapted or used for the construction of new knowledge and the acquisition of more sophisticated skills. It also provides the means for incorporating metacognitive activities into the subject matter, since students can take control of their learning by setting goals and monitoring their progress in attaining them with teacher as coacher and facilitator.

2.2.2 Engineering Design Process Facilitates Student-Centered Environments

Secondary vocational schools’ students are generally visual oriented learners, who have problems with theoretical models and methods and prefer to learn by experience and practice [5]. Engineering design process, as an instructional strategy has a great potential to build on the interests, the needs and the strengths of students in TVE, by engaging them in addressing a real problem or need in their area of study, (i.e. design and construction of an artefact or a part of a technical installation system). EDP can stimulate students of particular specialties, such as mechanical, electrical, computer, and the strengths of students in TVE, by engaging them in addressing a real problem or need in their area of study, (i.e. design and construction of an artefact or a part of a technical installation system). EDP can stimulate students of particular specialties, such as mechanical, electrical, computer, and electronics engineering technicians, to be involved in applying and learning theoretical knowledge (domain specific concepts, laws and principles, technical drawing, science and mathematics) by linking it to practical applications of their interest, within the content of relative workshop lessons. For example, mechanical engineering technicians may design and construct a fastener bolt for a camshaft bearing, while learning the concept of allowable stress in the strength of materials domain. Infusion of challenging problem solving activities, at the proper level of difficulty, not only evokes students’ intrinsic motivation to learn but they are willing to devote more time to learning as well [3]. Engaging in the engineering design process reveals students’ skills, beliefs, attitudes and preconceptions regarding the underlying theory, which as instruction proceeds can be adapted or used for the construction of new knowledge and the acquisition of more sophisticated skills. It also provides the means for incorporating metacognitive activities into the subject matter, since students can take control of their learning by setting goals and monitoring their progress in attaining them with teacher as coacher and facilitator.

2.2.3 Engineering Design Process Facilitates Knowledge-Centered Environments

As Bransford et. al. note in [3], environments that are solely learner-centered would not necessarily provide the kind of knowledge and skills required for thinking and solving problems effectively. It is the synergy of well-organized bodies of knowledge with a generic set of “thinking skills” or strategies that supports planning and strategic thinking like an expert, hence, curricula should be organized in ways that lead to conceptual understanding and foster an integrated understanding of the discipline.

Given that EDP provides a meaningful context for learning scientific, mathematical, and technological concepts [13], it can support effectively a knowledge-centered environment in technical and vocational education. It encourages students to develop an organized, understanding of important concepts in engineering domains, by specifying the contexts in and the conditions under which they are applicable, resulting in “usable” - that can be retrieved - knowledge. As Tate et al. [19] phrases it, by involving students in defining the root problem and the conditions needed for an optimal solution, engineering design enables in depth coverage of a topic and allows deep understanding of key discipline concepts. Introducing a concept in a specific engineering discipline, through EDP, elucidates its connection with other engineering disciplines in the curriculum, physics, chemistry, mathematics and the related practical/workshop lessons. Moreover, implementing EDP in TVE entails that students use industry quality materials, tools and recourses to solve an authentic problem, linking engineering theory with practice. As Grubbs and Strimel note in [11], this approach of infusing engineering in education, in contrast to engaging students in simple hands-on activities that lack authenticity, can lead to the development of new knowledge and can be more conducive to I-STEM_ED (integrated science, technology, engineering and mathematics education). In the aforementioned example of introducing the concept of allowable stress, except from the strength of materials course, the disciplines of machine elements, manufacturing technology, technical drawing and the practical course of manufacturing are involved. In addition to the mechanical properties of materials, students should consider requirements emanating from the camshaft system, constraints due to standardization, manufacturing, maintaining and repairing issues, as well as the graphical modelling of the designed bolt. Besides, especially for conducting analysis and modelling they will employ certain concepts and methods form science and mathematics (e.g., students may explore the relationship among force, cross section and stress through scientific inquiry to determine the corresponding mathematical model). Furthermore, the same concept can be introduced through different applications. In this way, overly contextualized knowledge is avoided and students can develop abstract representations of knowledge, which can help promote transfer [3]. Finally, by employing engineering design as instructional strategy students learn experientially the process that generates the technology, which
improves their technological literacy [21]. They understand when, where, and why to use new knowledge.

2.2.4 Engineering Design Process Facilitates Assessment-Centered Environments

Testing and evaluation of the solution for the purpose of optimization, the prominent characteristic of EDP [13], offer a powerful structure for assessment that provides feedback, reflection and revision. Teachers have the opportunity to identify problems that need to be addressed and to induce students to activities that promote metacognition. Metacognition, namely the ability to predict one’s performances on various tasks and to monitor one’s current level of understanding and decide when it is not adequate, affects drastically the transfer of learning to new settings and events. Besides metacognition promotes active learning, increases student achievement and turns them into lifelong learners [3].

2.2.5 Engineering Design Process Facilitates Community-Centered Environments

Engineering design process facilitates community-centered learning environments through different perspectives. Engineering in the real world demands collaboration that leverages the perspectives, knowledge, and capabilities of all team members to address a design challenge. Additionally, communication is essential to effective collaboration, to understanding the particular aspects and requirements of a problem and to explaining and justifying the final design solution [13]. Implementing EDP in the classroom raises corresponding demands. Hence, students should work in teams and feel free to explore what they do not understand, with teacher playing a coaching role and providing scaffolding when needed. Taking into consideration constraints exposures students in dealing with environmental, social and economic issues and legal regulations and organizing the content of engineering curricula around the design process, provides the context for establishing a community of collaborating engineering, science, mathematics, and practical courses teachers.

2.3 Engineering Design Process Supports Technical and Vocational Education to Meet Crucial Demands in the Twenty-First Century

Literature ascribes to engineering practices the ability to help students with: developing 21st cognitive competencies, acquiring kinds of knowledge, ways of thinking and acting and capabilities congruent with technological literacy, engaging in and aspiring to solve the major societal and environmental challenges that they will face in the decades ahead [11]. Besides, engineering design provides a meaningful context for learning scientific, mathematical, and technological concepts [13]. Furthermore, as we have discussed in the previous section, EDP can immerse secondary vocational engineering education students in creative learning settings consistent with the constructivist principles, where they analyse, carry out scientific inquiry and abstract mathematical models, make informed decisions and visualize and optimize solutions in order to solve an authentic problem. These experiences can result in useful learning, parallelized to that of experts [3]. The previous examination of constructivist learning environments based on EDP shows that they have a great potential to: provide students in TVE with integrated, “conditionialized”, well-organized knowledge; foster their ability to transfer and adapt acquired knowledge in new situations; provide them with metacognitive competencies; enable them to think about and solve problems with expertise; enhance their technological literacy; raise their awareness about various community issues; to encourage them to develop collaboration and communication skills. Imparting these learning outcomes renders EDP as an appropriate pedagogical approach that enables TVE graduates to meet crucial demands imposed on technicians by both workplace and working life in the 21st century.

2.3.1 Engineering Design Process Provides Theoretical Knowledge and Enhances Occupational/Technical skills

Literature emphasizes the importance of theory for TVE students in order to meet the needs of the workplaces in twenty-first century ([2], [6]). By promoting the kind of knowledge that an expert has, EDP helps students develop awareness of patterns of meaningful knowledge regarding their specific occupation. For example, as research has shown, expert electronic technicians were able to reproduce large portions of complex circuit diagrams much more quickly in comparison to novices. By remembering the structure and function of a typical amplifier, they were able to chunk several individual circuit elements, (e.g. resistors and capacitors), that performed the function of an amplifier [3].
2.3.2 Engineering Design Process Promotes Innovation Competence

It was von Hippel in 1988 [22], who, for the first time, through his work on sources of innovation highlighted the expertise, primarily based on practice and experience, that products users, such as key users of the machinery or aircraft industry, can bring into the development process. Since then a shift has been observed from considering innovation exclusively as a field for experts, to innovation networks involving a wide range of people with different educational and professional backgrounds. Shop floor people - technicians and skilled workers - are important innovatory actors who can contribute to both process and product innovation. The degree of their contribution depends on two factors: (a) their competence level for innovation, which is consisting of the general education level, the knowledge level of the subject field, and of experiences acquired during work at the workplace; and (b) their collaboration and communication skills that facilitate knowledge sharing with engineers.

2.3.3 Engineering Fosters Higher Order Thinking Skills/Key Competences

According to Lynch [6], U.S. high technical schools in the twenty-first century should be reformed towards promoting higher-order critical thinking skills. He defines a critical thinker as a person that has the ability to think creatively, make decisions, solve problems, visualize a solution, reason, analyse, interpret, and to continue to learn. Additionally, he notes that, “critical thinkers draw on a variety of resources and disciplines to solve problems, use standards of performance as a benchmark, and are intermittently independent and group reliant for assistance". This delineation of higher-order critical thinking skills is essentially in agreement with the description of the concept of key competences as it is referred to the work on technology and vocational education for sustainable development and was introduced as a move towards the growing “convergence” between vocational education and general education in Australia at the beginning of the 1990s [23].

2.3.4 Engineering Design Process Supports Sustainable Development Education

Promoting sustainable development is an expected feature of TVE in twenty-first century [2] that can allow new opportunities and roles in innovation, sustainable entrepreneurship and workforce for young people, in connection with both the protection of the environment and the adaptation to climate change [24]. Pavlova in [23] states that engineering design as a learning activity provides an excellent opportunity for realizing education for sustainable development (ESD) in technology and vocational education, since it involves students “in the process of formulating tasks, undertaking research and the development and evaluation of ideas, their presentation and realization”.

2.4 Engineering Design Process and Problem Solving Environments

Effective teaching and learning technology programs should enable knowledge building in the subject being studied, and should promote deep understanding of key concepts in the unit [3]. Problem solving environments (PSEs), through enabling computations, computational modelling, 2D/3D visualizations, simulations for scientific inquiry, data collection and scaffolding, seem ideal to support completely the functionality needed for a learning environment aligned with the learning principles and the demanding nature of EDP. Problem solving environments (PSEs) refers to a problem-oriented computing environment that supports the entire range of scientific computational problem-solving activity: from problem formulation, to algorithm selection, to numerical simulation, to solution visualization. Furthermore, a PSE should support collaboration among people separated in space and time, using a diverse set of codes and machines ([25], [26]).

Bransford et al. in [3] underscore the importance of interactivity of PSEs for efficacious learning, since it facilitates students, both individually and collaboratively, to explore and re-examine more fully specific parts of the environments, to test ideas and to receive feedback.

National Instrument’s LABVIEW Software is a prominent example of problem solving environment platform that supports engineering design curricula at the secondary level of education [27].

3 CONCLUSION

The new science of learning calls for rethinking what is taught, how it is taught, and how learning is assessed. Cognitive science research for teaching and learning has significant implications for technical and vocational education that are consistent with the changing working environment. In this article, we explored the constructivist nature of engineering design, the problem solving process of engineers, and discussed analytically it’s potential to support the development of student, knowledge,
assessment and community-centered learning environments. We also presented how delivering engineering curricula in TVE through these environments empowers its graduates to function successfully in both workplace and working life. Given that engineering challenges are tailored to the learners’ current levels of knowledge and skills, the advantages of learning environments employing engineering design process justify its portrayal as an appropriate constructivist pedagogical approach for technical and vocational education.

REFERENCES


