Competency-Based Learning for Improved Teaching and Learning the Thermodynamics Course for Chemical Engineering Students

Article history
Received
22 October 2024
Received in revised form
26 November 2024
Accepted
2 December 2024
Published online
30 December 2024

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Abstract
A proper design of the Competency-Based Learning (CBL) teaching and learning (T&L) environment is crucial for attaining the desired learning outcomes (DLOs), by chemical engineering students. This paper aims to analyze the successful practices of implementing common CBL elements into the existing OBE, ABET-accredited, chemical engineering curriculum, without disturbing the logistics of the current engineering programs. The paper describes and analyzes the implementation of a CBL environment in teaching thermodynamics, as an example of typical chemical engineering courses, at Higher Colleges of Technology (HCT), United Arab Emirates (UAE). The analysis considered teaching thermodynamics after and before CBL implementation, during the 2023-24 and 2022-23 academic years, respectively. The process included scaffolding steps necessary for engineering students to attain DLOs. In addition, the process may serve as a metric for educators in CBL implementation across other engineering courses.

Keywords: Competency-Based Learning (CBL), Chemical Engineering Courses, Thermodynamics.

Introduction

Globally engineering education programs strive to graduate quality engineers, equipped with discipline-related knowledge and the necessary set of skills, to face the current and future challenges of the job market (Rugarcia et al., 2000). Moreover, many researchers in the area of engineering education have been emphasizing that the implementation of advanced T&L philosophies is one of the key factors in meeting the increasing industrial demand for quality engineers (Felder and Brent, 2017; Felder, 2006; Felder et al., 2000; Boyer, 1990). Competency-based learning (CBL) represents one of these advanced student-centered learning methods. CBL is a very intriguing framework, and it has been gaining popularity in higher education, including engineering education, as well as in workplace training (Sistermans, 2020; Torres et al. 2015)

Higher Colleges of Technology (HCT) is the largest academic institution in the United Arab Emirates (UAE). Established in 1988, HCT has extended into 16 campuses distributed throughout the UAE. Currently, HCT accommodates more than 23 thousand students; they enrolled in 70 programs in Applied Media, Business, Computer Information Science, Engineering Technology & Science, Education, and Health Sciences. Female students make up more than 68% (or 14,669 students) of the total enrolled students, while the remaining 32% (or 6,903 students) are male students. Engineering Technology & Science (ETS) students make up almost one-fourth of the total (or 5,194 students), and there is a reasonable gender balance among them: 46% are female and the remaining 54% are male engineering students. Engineering students enrolled in 12 programs: Aeronautical, Aviation, Chemical, Civil, Electrical, Industrial, Logistics, Mechanical, Mechatronics, Marine, Marine Transport, and Maritime Engineering Technology (HCT website).

HCT offers a bachelor in chemical engineering technology program upon completion of 120 credit hours, distributed over 4 academic years. This workload covers four categories of courses: Engineering Core, Math & Natural Sciences, Electives, and General Studies. Like all other engineering programs, Chemical engineering is an ABET-accredited program, and it has been structured based on outcome-based education (OBE). Table 1 shows the Course Learning Outcomes (CLOs) (HCT- Chemical Technology). The first five POs are based on ABET Student Outcomes, which are related to the knowledge, skills, and behaviors that students gain through the study program, and describe what students are expected to know and do after graduation (ABET, 2019)]. The sixth PO reflects one of the HCT strategic undertakings.

HCT continuously seeks to improve its engineering programs, to graduate employable engineers with proper knowledge and the right skills. Continuous improvement has a double role: one is to meet ABET's requirement of continuous improvement, and the other is to observe one of HCT 4.0 strategic undertakings.

Table 1. Chemical engineering course learning outcomes (HCT- Chemical Technology)

Program Outcomes (POs)
1. An ability to apply knowledge, techniques, skills, and modern tools of mathematics, science, engineering, and technology to solve broadly defined engineering problems appropriate to the Chemical Engineering Technology. 2. An ability to design systems, components, or processes meeting specified needs for broadly defined engineering problems appropriate to the Chemical Engineering Technology. 3. An ability to apply written, oral, and graphical communication in broadly defined technical and non-technical environments; and the ability to identify and use appropriate technical literature. 4. An ability to conduct standard tests, measurements, and experiments and to analyze and interpret the results to improve processes. 5. An ability to function effectively as a member as well as a leader on technical teams. 6. An ability to develop and evaluate a business plan to transform an engineering design (systems, products, services, and solutions) into a business opportunity utilizing entrepreneurial skills and knowledge.

Thermodynamics

The year 1824 is considered the birthdate of thermodynamics, and scientists consider Sadi Carnot (1796-1832) as its founder; he published, 'Reflections on the Motive Power of Fire (1824)', a discourse on heat, power, energy, and engine efficiency. The book illustrates the basic relations between the Carnot engine, Carnot's cycle, and motive power. It marked the start of thermodynamics as a modern science (Perrot, 1998).

Thermodynamics is a branch of science that deals with the study of various forms of energy: heat, work, potential energy, kinetic energy, and internal energy. It is considered one of the core engineering courses; It applies to a variety of science and engineering topics such as chemical, physical, and mechanical engineering. For example, chemical thermodynamics is extremely useful in understanding and predicting the behavior of chemical reactions (e. g. digestion, and combustion). Chemical reactions involve changes in energy, enthalpy, and entropy, which are governed by thermodynamic principles. Table 2 shows the thermodynamics learning outcomes at HCT.

Thermodynamics can be incredibly challenging because it requires knowledge of complex mathematical equations and physics principles; it involves aligning theoretical and abstract concepts to a wide range of real-life applications.

Table 2. Chemical thermodynamics learning outcomes at HCT (HCT- Chemical Technology)

Course Learning Outcome (CLO)
1. Analyze the principles of thermodynamics and the properties associated with it. 2. Distinguish the different energy transfer mechanisms during chemical processes. 3. Examine the First law of thermodynamics and the relationships between the various forms of energy in closed and open systems. 4. Examine the entropy concept of the Second Law of thermodynamics in heat engines, heat pumps, and the spontaneity of Chemical reactions. 5. Analyze the ideal vapor compression refrigeration cycle.

Thermodynamics is perceived by many as an exceedingly difficult subject to study. There is a quote on learning thermodynamics, by Arnold Sommerfeld, "Thermodynamics is a funny subject. The first time you go through it, you do not understand it at all. The second time you go through it, you think you understand it, except for one or two small points. The third time you go through it, you know you do not understand it, but by the time you are so used to it, it does not bother you anymore" (Cited in Mulop et. al., 2012).

Its difficulty arises from confusing and complex concepts such as work, heat, temperature, specific heat capacity, internal energy, pressure, enthalpy, and bond energy, which are not easy to understand. On top of that, students' misconceptions about the difference, for instance, between heat and temperature, adiabatic and isothermal processes, types of systems and their relation to surroundings, etc. (Yang et. al., 2020)

For decades, many researchers have considered issues related to learning thermodynamics, and how to resolve them.

- Zabihian (2020) introduced 'Service Learning' as a pedagogical tool through which engineering students demonstrate their thermodynamics knowledge to public audiences. It is also known as an experiential learning approach, which could be integrated into education for a deep understanding of the subject matter rather than memorizing simple facts.
- Yang and colleagues (2020) presented two studies that used schema training to help students understand challenging engineering concepts, including thermodynamics concepts: One study used Chi's schema training framework to repair engineering students' misconceptions, which was developed by Chi and colleagues (2013).
- Mulop et. al. (2012) reviewed and analyzed approaches to enhancing the learning of

thermodynamics; between 2003 and 2009, they listed the efforts of 15 researchers on the matter: Computer Simulation of Experts (Lewis et al, 1993), Interactive Thermodynamic Cycles (Weston, 1998), Virtual Lab-Cyclepad (Baher et al, 1999), TESTTM Software (Kumpathy, 2002), A Virtual Power Plant Website (Kelly, 2002), Computer-based Active Learning Materials (Anderson et al, 2002), An online Thermodynamic Courseware (Ngo & Lai, 2003), Teaching with Physlets (Cox et al, 2003), Multimedia Engineering Thermodynamics (Huang & Gramoll, 2004), Experimental Apparatus (Abu-Mulaweh, 2004), Active Learning Environment (Hassan & Mat, 2005), Simulation Programs to Perform Virtual Experiments (Junglas, 2006), Virtual assembly- a web-based student learning tool related to multi-staging in compressors and turbines (Chaturvedi et al, 2007), A blended learning approach (Bullen & Russell, 2007), and Instructional courseware in thermodynamics education (Liu,2009), (Cited in Mulop et. al., 2012). In their analysis, Mulop and colleagues concluded that most of these methods have achieved a positive impact on T&L thermodynamics, although none of them is based on learning theories (Mulop et. al., 2012).

Methodology

Research Purpose

This paper aims to describe and analyze CBL implementation to improve the teaching and learning environment of a typical chemical engineering course. The paper used a Case Study in Thermodynamics.

Scope

The scope of the study is limited to analysis of the T&L environment of chemical thermodynamics, as an example, during the Fall and Spring semesters of the 2023-24 academic year; however, the analysis could be extended to other chemical engineering subjects.

Method

This paper uses mixed qualitative and quantitative methods to collect and analyze secondary data (Creswell, 2009). A documentary analysis of the subject of thermodynamics, before and after the implementation of the common CBL elements into the existing curriculum, was conducted. Documents were obtained from the HCT website. They include HCT's CBL guide, thermodynamics syllabus (CHE 3313), course assessment plan (CAP), assessment specification documents (ASD), HCT course assessment reports, and students' and teachers' evaluations of the overall subject. These documents were originally produced using various methods and intended for different purposes.

However, to develop realistic meanings of the gathered data, the analysis step was split into: First, this paper divided obtained documents, according to the purpose of analysis, into three parts, namely CBL implementation, assessment process, and students' performance (see Table 3). Second, the paper analyzed both obvious and deep written content, also called manifest and latent analysis, respectively (Bengtsson, 2016).

The pedagogical analysis of chemical thermodynamics was conducted, including students' performance, after CBL implementation, during the Fall and Spring semesters of the 2023-24 academic year (three courses). Their performance was tracked using both formative and summative assessments. The result compared with the students' performance, before CBL implementation over the 2022-23 academic year, also three courses.

Table 3. Purposes of Data Collection & Related Documents (HCT website)

Purpose of Analysis	Related Documents
CBL Implementation	• HCT's CBL guide (CBL principles, purposes, and practices) • Students' and teachers' evaluations
Assessment Process	• Syllabus of the course (CHE3313) • Course assessment plan (CAP) • Assessment specification documents (ASD)
Students Performance	• HCT course assessment reports • Instructors' feedback (formative assessment) • Instructors' feedback (achieved competencies)

Literature Review

Competency-based learning (CBL)

CBL has been around for more than a century ago; however, it has gained popularity, for a brief period, during the seventies of the 20th century (Gallagher, 2014). More recently, interest in CBL has increased significantly worldwide.

CBL is based on Ralph Tyler's (1949) curriculum and Spady's (1994) OBE. It is not easy to define the CBL term, and no single agreed-upon definition appears to exist (Torres et al., 2015). The lack of coherent definition of the CBL arises from the fact that researchers tend to use this term loosely and interchangeably with a wide range of other terms, known as competence-based synonyms: Criterion-Referenced (Glaser, 1963), Mastery-Based (Bloom 1968), Instructional Objectives (Major, 1970), Instructional Design (Gagne, 1974), Outcome-Based

(Spady, 1994), Performance-Based (Harden et al., 1999), Proficiency-Based, Standards-Based education, among others. Nevertheless, a reasonable CBL definition is stated by the glossary of education reform, "Competency-based learning refers to systems of instruction, assessment, grading, and academic reporting that are based on students demonstrating that they have learned the knowledge and skills they are expected to learn as they progress through their education" (Glossary of Education Reform- website). CBL is a teaching and learning framework that develops competencies based on an aligned curriculum, instruction, and assessment (Torres et. al., 2015). It is completely different from the traditional T&L methods regarding culture, pedagogy, and structure (Torres et. al., 2015; Sturgis et. all., 2018).

Unlike the traditional system, which focuses on time-based credit hours and academic grading for graduating its students, CBL is based on mastery-based grading where each student must demonstrate knowledge and skill to transfer acquired knowledge into an advanced context (Sturgis et. al., 2018). Takamine (2019) stated, "Competency-based education is an approach that evaluates the mastery of learning from a performance basis, rather than a seat-time basis".

The labor market underscores the importance of the 4-year degree program; however, the degree alone is insufficient for employment readiness (Clawson and Girardi, 2021). The degree needs to be associated with industry-relevant skills. DeMark and Kozyrev (2021) state that industry-related skills must be integrated into the learning process to support the upskilling and reskilling needs of the job market. Sturgis et. al. (2018 p11) state, "Competency-based structures place an equal emphasis upon academic knowledge, the skills to transfer and apply that knowledge (higher order skills), and a set of lifelong learning skills that enable students to be independent learners. Lifelong learning skills that empower students include growth mindset, metacognition, self-regulation, and other social and emotional skills, advocacy, and the habits of success" (Sturgis et. al., 2018 p11).

CBL has three basic components: the experiential learning approach, the competency-oriented courses and interventions, and the competency assessment process (Torres et. al., 2015; Gervais, 2016). Also, the CBL framework contains many distinguishable elements; However, this paper considers the four common elements of CBL, as defined by Torres et. al. (2015), "1) Students must demonstrate mastery of all required competencies to earn credit or graduate. 2) Students advance once they have demonstrated mastery, and students have more time to demonstrate mastery if needed. 3) Students are assessed using multiple measures to determine competency. 4) Students earn credit toward graduation in ways other than seat time and course taking."

Theoretical Perspectives

The CBL environment is underpinned by two principles: Constructive Alignment (CA), and How People Learn (HPL) framework.

(i) Constructive Alignment

Biggs has developed the CA framework based on Ralph Tyler's (1949) model. Biggs (1996) claims that CA is a system that integrates all aspects of teaching and assessment to achieve high-level learning. In other words, the constructivism framework should guide all instructional design stages: from deriving curriculum objectives and deciding teaching/learning activities to assessing students' performance. According to Biggs (1996), CA has two elements: First, the 'Constructive' element, which refers to students 'constructing meaning' by using relevant learning activities, while teachers function as learning facilitators. The second is the 'Alignment' element, which refers to the teacher's role, as a course designer, in developing learning environments suitable for achieving intended learning outcomes. CA aligns desired learning outcomes (DLOs) with teaching and learning activities (TLA) and assessment tasks (AT), in the following order: i. Defining the desired learning outcomes (DLOs); ii. choosing teaching/learning activities likely to lead to DLOs; iii. assessing students' actual learning outcomes to see how well they match what was intended; and iv. arriving at the final grade (Biggs, 2014; Biggs and Tang, 2011). It is worth noting that the CA model and CBL environments complement each other.

(ii) How People Learn (HPL) Framework

The HPL framework is utilized to analyze and design T&L environments through four interrelated perspectives: Learner-centered, knowledge-centered, assessment-centered, and community-centered (Bransford et al., 2000).

Learner-Centered: this term refers to T&L environments that pay careful attention to the knowledge, skills, attitudes, and beliefs that learners bring to the educational setting (Bransford et al., 2000). In other words, educators need to understand and work with the prior knowledge, skills, attitudes, and beliefs of the learners that they bring to their formal educational setting. Also, teachers should acknowledge the effect of culture and language barriers on students' performance and be ready to address any negative effects. In learner-centered environments, teachers are required to monitor learner progress, maintain their engagement, and challenge them by providing manageable tasks (NRC-HPL, 2000). Moreover, educators should understand the misconceptions of novice learners, due to their prior knowledge and learning style, and how to overcome these misconceptions. Theories of conceptual change (CC) assume that a learner's conceptual understanding may dictate his or her learning. Yang et al. (2014) stated, "… what an individual learns is at least partially controlled by what he already knows".

Knowledge-Centered Environments: Knowledge-centered focuses on in-depth coverage of subject matter and not only factual memorizing, and how the acquired knowledge is used or transferred into a new context. HPL discussed the difference between experts and novices as well as knowledge transfer to new contexts. Following the HPL framework, successful implementation of CBL principles should result in the transfer of learning from students' previous academic experiences so that students become adaptive experts in their areas of study (NRC- HPL, 2000).

Assessment-Centered Environments: Assessment must emphasize understanding and not just memorizing facts and/or procedures, despite their importance (NRC- HPL, 2000). There are two types of assessment: First, summative assessments measure the students' outcome at the end of specific learning activities using, for instance, mid-terms and finals given during or at the end of a semester or academic year, respectively. The other type is formative assessments such as students' self-assessments, peers' assessments, and teacher's comments on the student's progress during learning activities, including classwork, tutorials, etc. Formative assessments are given to help both teachers and students monitor students' progress toward their learning objectives (NRC- HPL, 2000). Bransford et al. (2000) state, "Formative assessments—ongoing assessments designed to make students' thinking visible to both teachers and students—are essential. They permit the teacher to grasp the students' preconceptions, understand where the students are in the 'developmental corridor' from informal to formal thinking, and design instruction accordingly". Other formative assessment features are that they must be frequent, learner-friendly, promote deep understanding, and support active learning (NRC- HPL, 2000).

Community-Centered: HPL considers two levels of communities. One level of classrooms and schools where students, teachers, and administration interact among themselves; and the other level of community is between classrooms/school and the broader community, including homes, community centers, after-school programs, and businesses (NRC- HPL, 2000). The different social norms imposed by different schools may greatly affect learning. Learning tends to improve when classrooms and schools encourage students' participation, and freedom to make mistakes and ask questions while learning (Brown & Campione, 1998; Cobb et. al., 1992). Opposite norms, discouraging asking questions to understand the materials or making mistakes, while exploring new concepts, negatively impact learning (Holt, 1964).

The next section illustrates how the CBL implementation follows the constructive alignment principles and the four perspectives of the HPL framework.

Implementation of CBL Elements into Current Curriculum

As shown in Figure 1, HCT has developed a CBL framework consisting of three building blocks: Principle, Purpose, and Practice.

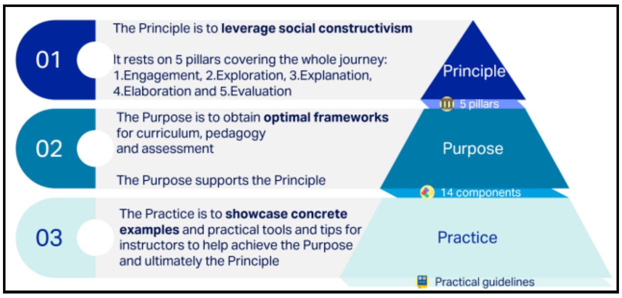

Figure 1. HCT's CBL framework (HCT's CBL Guide)

Principle

The core Principle in leveraging the CBL is social constructivism, based on Vygotsky's social learning theory of 1962. This theory emphasizes the collaborative nature of learning, which means that in addition to their cognitive stage, learners develop knowledge from people's interactions, among themselves, their culture, and society (Community-Centered). Social constructivism is a student-centered learning philosophy, where the learner actively constructs and stores models, based on the learner's prior knowledge, and the educator acts as a facilitator who encourages students to actively achieve in-depth knowledge (deep understanding).

HCT established a practical CBL educational model by pairing principles of constructivism and the 5E Instructional Model (Bybee, 2006): Engagement, Exploration, Explanation, Elaboration, and Evaluation. Noting that 5E plays a crucial role in curriculum development.

Purpose

The Purpose of the CBL, at HCT, is to guide instructors to apply the 5E to the three instructional elements: Curriculum development, pedagogy approach, and assessment strategy.

(i) Curriculum Development

In developing the curriculum, the CBL model at HCT focuses on matching competencies to the skills demanded by the labor market. A CBL curriculum is outcome-based and includes competencies required by the job market. At HCT the OBE curriculum tends to teach thermodynamic properties of pure substances, properties and the equations-of-state of ideal and real gases, the laws of thermodynamics and chemical thermodynamic principles, typical thermodynamic cycles including representation on a T-S diagram, and the performance of a steam power plant. Class activities consist of theory, demonstration, problem-solving, and laboratory work to reinforce theoretical concepts. Student learning is supported through a range of T&L methodologies including textbooks, physical labs, projects, tutorials, and assignments (CHE 3313 Syllabus).

The main objective of the thermodynamics course is to understand the behavior of systems at the macroscopic level. It gives the foundation for heat engines, heat pumps, refrigerators, power plants, chemical reactions, and many other important concepts. Its applications in chemical engineering include, but are not limited to, predicting the behavior of chemical reactions, process design, process control, and plant operation. Nevertheless, incorporating CBL features (HCT's CBL Guide) helped to identify and align competencies with industry-related skills.

(ii) Pedagogical approach

The pedagogical or instructional approach focuses on delivering practical CBL curriculum content. The pedagogical approach combines the Social Constructivism theory and the 5E Instructional Model to achieve the proper delivery of the CBL curriculum, including knowledge, skills, and attitude, and impart a mastery of knowledge through activities such as work-like simulations and industry exposure. At HCT, the pedagogical approach aims to prepare students for their after-school lives by blending theoretical knowledge with practical learning. This included real-life individual and group projects, industry-prescribed competencies, field visits, and internships.

(iii) Assessment Process

The assessment of teaching has two objectives: One is evaluation of teaching effectiveness (summative assessment), and the other is improvement of teaching (formative assessment). Pellegrino et al. (2014) identify three assessment purposes, "i) assessment to assist learning (formative assessment), ii) assessment of individual achievement (summative assessment), and iii) assessment to evaluate programs (administrators and policymakers' assessment)". These three types of assessment are also known as assessment for learning (AfL), assessment of learning (AoL), and assessment as learning (AaL), respectively (Rugarcia and Felder, 2000). Therefore, assessment tools, formal and/or informal, are developed aiming at the specific purpose of the assessment. For instance, the purpose of the traditional testing is to meet accreditation requirements: Formative assessment, including mid-terms and in-/out- of class assignments is required to enhance students' performance in the final summative assessment (Lord & Chen, 2014).

Huang et. al., (2022) identified a competency-based assessment strategy to determine developed competencies in three domains, namely knowledge, skills, and attitude. These three domains represent the components of engineering education. Rugarcia et. al. (2000) wrote, "Knowledge is the database of a professional engineer; skills are the tools used to manipulate the knowledge in order to meet a goal dictated or strongly influenced by the attitudes".

CBL formative assessment, an assessment for learning, is designed to help each student, individually, to master learning objectives, including his/her ability to transfer knowledge into a new context, the higher order skills of analysis, synthesis, and evaluation (Huang et. al., 2022). Therefore, to capture students' developed competencies, HCT's current assessment strategy includes the above-mentioned three types of assessment, as shown in Table 4, which is different from the previous assessment scheme. The previous traditional, timely-based, assessment scheme was based on the summative assessment that emphasized the lower portion of Bloom's taxonomy: memorization, comprehension, and application. The previous summative assessment scheme included the following assessment items: Quizzes (15%), midterm (20%), lab work (20%), projects (15%), practical final (10%), and theoretical final assessment (20%).

Table 4. Current assessment process of thermodynamics subject

Assessment Item	Weight	Assessee	Assessor	Assessment Type
Class Work, Presentation	--		Teacher & Peer	Formative Assessment
Lab Work	--		Lab Instructor	
Assignment, Service Learning	--		Teacher	
Lab Reports	15%	Team	Lab Instructor	Summative Assessment Toward (Final Grade)
	10%	Individual	Lab Instructor	
Midterm	35%	Individual	Teacher	
Final	40%	Individual	Teacher	

Practice

By utilizing the HCT's CBL framework, instructors can strengthen their CBL practices in terms of delivery, assessment, and promotion of education. Effective CBL implementation promotes a student-centered approach to learning outcomes and prepares graduates for their after-school lives. Table 5 shows the distribution of 14 Purpose components throughout the 5E pillars. Effective implementation of each component ensures that students acquire the practical skills (competencies) necessary for the job market.

Table 5. CBL principles (5E), purposes, and required competencies (HCT's CBL Guide)

5Es (i to v) & Purposes (1 to 14)	Competency
i. Engagement: 1) Institution & industry teaching 2) opportunity for collective learning, 3) application of real-world contexts. ii. Exploration: 4) Potential for empirical skill development, 5) readiness for contextual use of technology, 6) engagement of diverse stakeholders. iii. Explanation: 7) Potential for students to participate. iv. Elaboration: 8) Improve by building on the existing components, 9) opportunity for students to grow, 10) degree of personalization,11)Communication professionalism. v. Evaluation: 12) Degree of adoption formative assessments, 13) self-assessments & peer assessments, and 14) faculty and industry stakeholders' assessment.	Critical thinking Research Innovation Teamwork Leadership Problem-solving Communication Knowledge sharing Organizational skills Self-awareness

Effectiveness of CBL Implementation

Developed Skills

HCT has formed an Industry Advisory Committee (IAC) that is in charge of collaboration between HCT and industry in various areas such as internships, applied research opportunities, senior capstone real-life projects, industry requirements, etc. The CBL implementation helped students to develop the required competencies for the job market, as summarized in Table 5 above while improving their thermodynamics learning. These industry-relevant competencies have been identified through IAC biannual meetings.

Students' Performance

This section compares and discusses students' performance during the 2023-24 and 2022-23 academic years, before and after introducing the CBL elements into the thermodynamics curriculum. Incorporating the CBL elements in teaching and learning thermodynamics has enhanced students' performance. Table 6 illustrates the grade achieved by students over two academic years 2023-24 and 2022-23, respectively. After CBL implementation, during the Fall and Spring of 2023-24, the success rate was 97% or 28 out of the total 29 students have passed the thermodynamics course (CHE 3313), with an accumulative GPA of 2.64/4.0. The percentage of students who obtained grades 'A' was more than 28%; while those who obtained grades 'B' and 'C' were 34% and 31%, respectively. This performance has significantly exceeded students' performance during the previous 2022-23 academic year, before CBL implementation. Back then, only 5% achieved an 'A' grade, 34% achieved a 'B' grade, 36% achieved a 'C' grade, and 16% achieved a 'D' grade. Noting that the total success rate during the 2022-23 academic year was about 95%, with an accumulative GPA of 2.24/4.0.

Table 6. Students' performance during 2023-24 & 2022-23 (HCT course assessment report)

Grade	Academic Year 2023-24 (3 courses after CBL)	Academic Year 2023-24 (3 courses before CBL)
cGPA	(2.64/4.0)	(2.24/4.0)
A & A-	8 (28%)	2 (5%)
B+, B, B-	10 (34%)	15 (35.5%)
C+, C, C-	9 (31%)	16 (38%)
D	1 (3%)	7 (16.5%)
F	0	0
Withdraw	1 (3%)	0
Total	29 (100%)	42 (100%)

Students' Course Evaluation

Students gave their feedback on applying CBL as a tool for enhancing students' learning of thermodynamics. They answered 11 out of 13 question items, as shown in Table 7. These questions are related to course learning outcomes and how they are covered, assessment strategy, level of academic challenge, educational resources, T&L methodologies, lab sessions and the practical space, and the safety of the laboratory. Students gave no feedback on how much the course learning outcomes were covered and the overall course experience. Students' ratings favored most of the questions (above 80% rating), except for the level of academic challenge (only 62.5% rating) and appropriateness of the T&L methodologies (about 68.7% rating).

Overall, students were remarkably positive about the CBL enhancing the learning of thermodynamics. Their positive remarks were evident during formative assessment items, and by assessor evaluation of skills developed by students.

Challenges and Limitations of the Study

One of the main challenges during the CBL implementation was the faculty's role. To ensure faculties' positive impact, HCT has provided necessary professional development to help them recognize the CBL benefits and overcome any resistance to change.

Moreover, CBL implementation has occurred gradually.

The study also concluded that CBL implementation has improved student thermodynamics learning outcomes, in terms of knowledge and competencies. This conclusion was drawn from limited data, only three classes before and three after the CBL implementation, over two academic years. Nevertheless, this limitation did not adversely affect the conclusion, because the paper has collected and analyzed many related documents, see Table 3, and all of them led to the same conclusion that CBL implementation improved student thermodynamics outcomes. Yet, the analysis of the CBL implementation could be expanded to a wider range of engineering courses to generalize it as a model for similar situations.

Table 7. Students' course evaluation (adopted_HCT course assessment report)

Question Item	Satisfaction
1. Alignment of assessments to the course learning outcomes	81.25%
2. Availability of additional educational resources	81.25%
3. Level of academic challenge	62.50%
4. The course textbook/ eBooks	81.25%
5. The facilities provided for this course	75%
6. Appropriateness of the teaching and learning methodologies	68.75%
7. The extent to which the course learning outcomes were covered	--
8. Appropriateness of lab/practical sessions to enhance learning	87.50%
9. Functionality of equipment/ resources in the lab/practical space	81.25%
10. Adequateness of lab equipment/ software resources/practical space	91.67%
11. Level of lab/ instructor support to deliver the lab/practical sessions	81.25%
12. Safety of the lab/practical space	93.75%
13. Overall course experience	--

Conclusion

Difficulties in learning basic concepts of thermodynamics have been investigated by many researchers who have made vast efforts to enhance students' learning of thermodynamics. This article is about implementing CBL elements that helped students improve their performance in learning thermodynamics. The improvement has been evident in the student's performance and positive remarks.

Acknowledgement

The author would like to acknowledge the instructors from the Department of Chemical Engineering, at Higher Colleges of Technology, who provided their positive feedback while implementing the CBL elements in teaching and learning thermodynamics.

Conflict of Interest

The author declares no conflict of interest.

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