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Abstract

Preliminary research showed that the learning process could have been more optimal, and this led to the research to develop a TEFA Model with the PBL concept as a valid, practical, and effective method of improving the problem-solving and communication skills of Automotive Vocational Education students. The process involved using the Research and development approach through the application of 4D development procedures of Defining, Designing, Developing, and Disseminating. The study resulted in the TEFA-PBL model with seven learning syntaxes. The syntaxes were (1) troubleshooting the problem, (2) organizing the order, (3) collaborative problem solving, (4) executing an order, (5) quality control, (6) presentation and discussion, and (7) assessment. Furthermore, scenarios were generated to guide the learning activities of lecturers and students directed towards achieving fundamental and global 21st-century automotive vocational skills such as good problem-solving, communication, and collaboration skills. The syntax and scenarios of the learning model produced were feasible, valid, and practically applicable to produce graduates with ready-to-use and competitive skills. It, therefore, signifies that the TEFA-PBL model developed is an innovative solution to improve the quality of automotive vocational learning at different levels, especially universities, to produce graduates with ready-to-use and competitive skills.

Introduction

The prevailing Industrial Revolution 4.0 has changed all aspects of life, including the interaction between humans and machines (Himmetoglu et al., 2021; Pyo et al., 2021). It is indicated by the transformation of information technology, cellular communication, e-commerce, automotive technology, social media, internet in communication, Big Data, Internet of Things, Cyber-physical systems, Collaboration Systems, Cloud Computing, and Intelligent robots (Moraes & Lepikson, 2017; Roblek et al., 2016). There is, therefore, the need for higher education institutions to anticipate these rapid technological developments in order to design curriculum and educational activities following the highly competitive business and industry and also to stay in line with developments in information and technology because considering the changes in the work processes due to the industrial revolution (Ciolacu et al., 2019; Hermann et al., 2016). It is more critical for Technical and Vocational Education and Training (TVET), which focuses on providing human resources required to survive in the digitalization era but observed to be faced with the challenges and responsibilities of producing employees that possess the skills needed in the industry (Chou et al., 2018; Skilton & Hovsepian, 2018). It was discovered that the abilities required for employees entering the industry are already available at the middle and high levels (Shahroom & Hussin, 2018).

The previous research also showed that an individual needs to have multiple skills or abilities to find opportunities open to future careers to become an automotive expert capable of competing in the 21st-century labor market (Helper et al., 2019; Pete & Fogarty, 2017). These include good communication, problem-solving, innovation, creativity, and critical thinking skills (Chou et al., 2018; Zhou et al., 2015). There is, however, a gap between expectations and reality, with several competencies observed to be currently at the minimum among automotive engineers, as indicated by their lack of the skills mentioned above. This statement means there is a need to ensure that educational programs include more opportunities for students to develop these soft skills (Erol et al., 2016; Naslund & Filipenko, 2016). It is necessary because most engineering graduates have little knowledge of real-world problem-solving and communication skills but have more understanding of their textbooks (Joshi et al., 2020; Mcloone et al., 2016). Moreover, it was discovered that traditional higher education learning methods, such as lectures, cannot adequately prepare students to transition from conventional to professional classes (Mcloone et al., 2016; Naslund & Filipenko, 2016).

The broad skills needed by an automotive expert include communication, problem-solving, collaboration, innovation or creative thinking, and critical thinking in that order (Belousov et al., 2020; Zaccaro, 2006; Wagino et al., 2023). Meanwhile, previous research has discovered that thinking skills are one of the life abilities that need to be developed through the educational process (Belousov et al., 2020). Another research by Shaw (Shaw, 2001) showed that problem-solving is the second skill after communication is lacking among the students, followed by creative thinking and critical thinking.

As a result, it is vital to develop innovative educational techniques that transform the learning process for the better to improve students' problem-solving and communication abilities. Choosing the appropriate learning model can help to solve this problem (McConnell et al., 2016). To improve future engineering students' ability to communicate, think critically, think creatively, and solve problems, the learning model must be shifted from teacher-centered to student-centered so that students can be more active and creative in the learning process (Ulger, 2018; McLoone et al., 2016). The TEFA-PBL learning model is a student-centered learning paradigm that successfully provides student feedback (Mubuuke et al., 2016). The primary purpose of TEFA learning is to improve knowledge, problem-solving, thinking abilities, and intellectual skills in an environment similar to that found in business (Oestreicher, 2019). A recent study showed the efficiency of PBL in enhancing thinking capacities such as problem-solving skills (Kadir et al., 2016), communication skills (Pratama et al., 2018), and academic accomplishment (Foster et al., 2017).

TEFA model is not a new learning approach, but the inclusion of the Problem-Based Learning concept was observed to be an innovative development for automotive vocational learning (Syed et al., 2021). The TEFA-PBL was developed through the successful combination and integration of concepts from different educational theories and operating them in a coherent series of activities to assist students in learning collaboratively and actively to solve real motorized vehicle problems (Elkins, 2009; Moallem et al., 2019; Watson, 2010). It means it is a skill education process designed and implemented based on accurate job procedures and standards of the automotive industry to produce services that match the market's or consumers' demands (Maksum & Purwanto, 2022). It is also a learning model that provides opportunities for students to develop problem-solving and communication skills. Therefore, this research was conducted to improve automotive education students' problem-solving and communication skills by developing a teaching factory model with a PBL concept. It is important to note that including the PBL concept in the model is the novelty of this research.

Teaching Factory (TEFA)

Teaching Factory Learning is a production/service-based model that simulates industry standards and procedures, creating an environment similar to the industry (Welsh et al., 2020). The successful implementation of TEFA requires active involvement from industry stakeholders to assess the quality of education outcomes (Diwangkoro, 2020). It should also involve the government, local authorities, and stakeholders in the formulation, planning, execution, and evaluation of Teaching Factory (TEFA) (Louw & Deacon, 2020). This teaching method provides services or products based on established industry procedures and standards, applied according to the current industrial situations, and typically implemented within vocational school environments (Mavrikios et al., 2018). The fundamental concept of Teaching Factory is to replicate the actual production environment of industries within the practical space of the learning process (Metternich et al., 2018). This real-life production experience is crucial for enhancing competency-based learning that aligns with everyday industrial practices (Mavrikios et al., 2019). Students engage in real work based on the required competencies, bridging the gap between industry needs and school knowledge (Mourtzis et al., 2018). Ultimately, combining theory and practice with natural products, the Teaching Factory learning model benefits schools, students, teachers, and regional economic growth (Welsh et al., 2020).

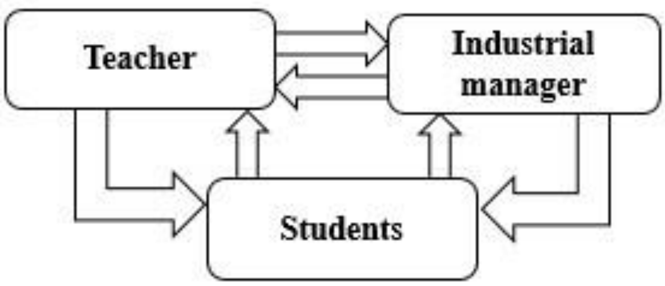

Figure 1. Interaction Concept between Students, Teacher, and Industrial Manager

The Teaching Factory draws inspiration from *Work Based Learning* (WBL) and experiential learning theories. It emphasizes the technology concept that evolves within companies, aligning with technological advancements

(Chryssolouris et al., 2016). The model involves interaction, exploration, field experience, and problem-solving among educators, students, and companies, as shown in Figure 1.

Innovative vocational education learning technologies and productive practices are educational methods oriented toward managing student participants to meet the needs of the business/industry world (Diwangkoro, 2020). Close partnerships between educational/training institutions and relevant companies are crucial (Wahjusaputri & Bunyamin, 2022). Teaching Factory implements the Work Based Learning model, designed and carried out based on actual working procedures and standards to produce goods or services that meet market demands (Louw & Deacon, 2020). The products produced can be sold or used by the community, schools, or consumers. This statement is contrary to the old paradigm of production-based learning, which prioritized quantity over the use or marketing of the produced goods, merely focusing on value within the teaching and learning process. The Teaching Factory approach fosters an ideal cooperation between the business/industry world and vocational educational institutions, establishing an interrelated and mutually beneficial relationship.

Problem-Based Learning (PBL)

PBL is a learning model that uses problems as the first step to integrating new knowledge (Bosica et al., 2021; Moallem et al., 2019; Moust et al., 2021). It was also described by McConnell et al. (2016) and Wong (2017a) as the learning method that focuses on presenting problems, actual or simulated, to students to solve through a series of studies on the theories, concepts, and principles learned from different fields of science.

Moreover, PBL is defined as a student-centered learning model that uses real-life problems and situations to impart knowledge to students (McConnell et al., 2016; Naslund & Filipenko, 2016). The concept was also observed by Torp and Sage (2002) and Fernandes (2021) to be a process used in fulfilling the demands of a new paradigm in education that emerged in the era of the knowledge-based economy caused by the explosion of information and globalization. PBL was initially introduced into the medical program at McMaster University, Canada, and later improved and strengthened to be implemented in sixty other medical schools (Zhou, 2020) and other fields such as commerce, education, architecture, law, engineering, and social work (Naslund & Filipenko, 2016). It has also been implemented in other learning environments, such as distance education, online learning (Aslan, 2021), diploma programs, secondary schools, and elementary schools (Oestreicher, 2019; Reed et al., 2021). PBL has also been introduced to new and more specific fields such as sports therapy (Wright et al., 2015), biomechanics (Wallace et al., 2020), visual arts education (Ulger, 2018), radiography education (Lawal et al., 2021), mathematics preservice teacher education course (Bosica et al., 2021), and engineering education (Joshi et al., 2020).

PBL allows students to learn the basic principles of a subject or competence in the context of its importance and also to solve real situations and problems (Wong, 2017a) through effective and efficient analysis. The methods involved include practicing, using, and developing mastery, group collaboration, critical thinking, and self-study skills, which are later applied to solve problems (Ulger, 2018; Wallace et al., 2020). The success of PBL depends on the ability of students to combine all these skills under the facilitation of teaching staff or facilitators (Fernandes, 2021; Wong, 2017b). This aspect is considered necessary because their level of engagement with learning influences the final result of presenting and providing solutions to any problem they face in real life (Joshi et al., 2020; Waite et al., 2020).

Problem-Solving Skills

Problem-solving involves defining problems, determining their causes, prioritizing, selecting solutions, and implementing them (Belousov et al., 2020). The concept was defined as reorganizing concepts to overcome difficulties or obstacles and achieve goals (Jonassen, 2010). It was also explained by Zaccaro (2006) to be an activity initiated through an unknown variable and completed by determining the variable through the best method. Furthermore, Belousov et al. (2020) stated that the prerequisites needed for the process include knowledge, experience, learning skills, motivation, and communication, while Jonassen (2010) showed that problem-solving skills are recognizable, teachable, and are classified as a discipline with an understandable structure.

Problem-solving has been reported to be a type of intellectual skill with a higher degree and more complexity than others (Jonassen, 2010; Mazorodze & Reiss, 2019). It was associated with the argument of Jonassen (2010) that it requires complex or high-level rules, which can be achieved after mastering defined rules and concepts by understanding concrete concepts and differentiating skills (Belousov et al., 2020). Problem-solving skill was also stated by Larson (Larson, 2012) to be a prerequisite for human survival because several situations encountered in everyday life requires solving problems (Asigigan & Samur, 2021). Moreover, intelligence, which is a mental process of solving problems, is also needed in daily living (Treffinger, 2000) and has been reported to be the primary goal of the educational process (Kadir et al., 2016). This statement led to the definition of the concept as the ability to solve a problem systematically (Dierdorff et al., 2001). It was discovered that this skill, in combination with solid science knowledge, is always highly valued for jobs in the science industry (Mazorodze & Reiss, 2019; Shaw, 2001). Moreover, the pattern of results from the research on final-year vocational students showed the ability of PBL to create empowering conditions for learning through greater access to opportunities, information, support, and resources (Aslan, 2021; Mazorodze & Reiss, 2019). The students also reported excellent vocational problem-solving skills after studying with the PBL model (Ting et al., 2021).

Rapid growth in the automotive vocational environment leads to the deliberate design of TEFA with the PBL concept to ensure students acquire the problem-solving skills needed for the disturbances in motor vehicles (Elkins, 2009; Oestreicher, 2019; Webb, 2010). It was discovered to generally increase the efficiency of the students concerning their problem-solving and scientific reasoning skills (Pete & Fogarty, 2017; Ofianto et al., 2022) and the same was also reported by Yuberti et al. (Yuberti et al., 2019) and Helmi et al. (Helmi et al., 2017). Moreover, TEFA-PBL is also expected to improve students' problem-solving skills in automotive vocational subjects (Elkins, 2009; Oestreicher, 2019; Watson, 2010). Its complete conceptual framework implements three theories: information processing, independent learning, and scaffolding.

According to Zaccaro (2006) and Treffinger (2000), problem-solving skill includes (1) understanding and representing problems, (2) collecting and organizing relevant information, (3) building and managing action plans or strategies, (4) using different tools, and (5) reasoning, hypothesis testing, and decision making. It is considered necessary in PBL because students must solve problems systematically and gradually to arrive at solutions (Aslan, 2021; Ting et al., 2021), thereby leading to learning (Kadir et al., 2016). The process also allows restructuring of existing knowledge into new ones (Helmi et al., 2017; Yuberti et al., 2019). It is also important to note that the learning aspect of the PBL is more expanded compared to lectures, and this provides an avenue for the students to learn more (Cho & Kim, 2020; McConnell et al., 2016; Naslund et al., 2016)

Communication Skills

Communication skill is another critical element of TEFA-PBL because it involves peer interaction in searching for information and solutions (Barker, 2019) and during the writing and presentation processes (Jdaitawi, 2020; Ting et al., 2021). Previous studies have shown the ability of the PBL model to improve students' communication skills (Farmer & Wilkinson, 2018; Itatani et al., 2017) through group learning and presentations during the TEFA-PBL implementation process (Deep et al., 2019; Herdini et al., 2019).

Communication is the sharing of information, messages, ideas, thoughts, and feelings between a sender and receiver (Barker, 2019; Surya et al., 2018). It involves creating communicativeness between the teachers and students in a learning environment based on the learning objectives (Halvorsen, 2021; Kumar & Lata, 2015). Educational communication is classified into primary and secondary (Shah, 2021), and the primary aspect involves face-to-face communication and situations between teachers and students, leading to immediate response and direct feedback. It is considered more effective and efficient than the secondary aspect (Barker, 2019; Surya et al., 2018) which happens between the communicator and the communicant at a relatively far distance without face-to-face contact (Halvorsen, 2021; Kumar & Lata, 2015; Shah, 2021).

Communication skills always focus on the delivery and transmission of knowledge (Farmer & Wilkinson, 2018; Itatani et al., 2017) and are considered the essential skill to be developed and used by students in PBL (Baile & Blatner, 2014; Latif et al., 2018) because the lecturer only serves as a facilitator and the students are expected to play a more proactive role in the sessions (Moallem et al., 2019; Moust et al., 2021) by reading out the problem, getting feedback from their peers, finding solutions, and finally making group presentations (Bosica et al., 2021; Torp & Sage, 2002). All these activities, however, require communication skills (Pratama et al., 2019; Warnock & Mohammadi-Aragh, 2016).

Communication skill is divided into two parts, which include oral and written, but this research focused on the oral aspect in the form of presentation. It was observed to be characterized by (1) correct understanding of the subject of communication skills, (2) learning by looking at the examples, (3) learning by doing, (4) learning by receiving feedback from others, and (5) learning by applying out-of-classroom, social, or professional situations (Barker, 2019; Surya et al., 2018). This model generally emphasizes students observing and exemplifying communication skills, practicing them, collecting feedback from their friends, and applying them in everyday life (Halvorsen, 2021; Kumar & Lata, 2015). Meanwhile, the students must use these skills regularly to master them proficiently. Notably, they generally develop their communication skills during the PBL process (Beagon et al., 2019; Elzomor et al., 2018).

Method

Experimental Procedure

A mixed method, which is also known as Research and Development (R&D), involving both qualitative and quantitative approaches, as explained by Creswell and Plano (2011), was used in this research. Integrating two or more methods increases confidence, provides valid results, and ensures the problem is not just a methodological artifact (Ladner, 2019). It is possible because qualitative methods are commonly used to gain a better understanding of the results of quantitative research (Creswell et al., 2011), as observed in the problem-based learning model previously developed for automotive vocational education (Maksum & Purwanto, 2019; Maksum et al., 2019).

The TEFA-PBL model development procedure uses an instructional design method with a 4D procedure approach consisting of 4 main stages: define, design, develop, and disseminate (see Figure 2). The level of effectiveness is measured by increasing cognitive aspects, problem-solving skills, and communication skills. 5 experts validated the product model according to their respective expertise, and the results of the validation were analyzed, namely the construct of the model syntax, which was developed by adopting the concept of Confirmatory Factor Analysis (CFA) using Lisrel 8.80 software and the Aikens V value to validate the product content model.

Testing the Effectiveness of Implementing the TEFA-PBL Model

The effectiveness test was initiated with a quasi-experimental pretest between the control and the experimental classes in the quantitative dimension (Figure 3). The data collection and experimental processes were completed within 10 working weeks, with the pretest activities for the control and experimental classes conducted. Both groups were informed about the general and specific learning objectives before implementing the study in the first week as presented in Figure 3. It was followed by the experimental procedures for the next eight weeks with the TEFA-PBL model applied for the experimental class while the Teacher-Based Instruction was used for the control class. A post-test was conducted after the completion of the experimental procedure to measure Learning Achievement, Problem Solving, and Communication Skills achieved by students after ten weeks of learning.

Measuring and Data Collection Tools

Learning Achievement Test

An instrument was developed to test the learning objectives achieved by the students. It contained 10 question items for each purpose, leading to 50 questions for the pretest and 50 for the post-test with the same difficulty. The questions were validated by four experts, leading to the revision of six and the subsequent application of the instrument on 30 students not used as the subjects. The difficulty and discrimination indices for all items were calculated, and 45 questions were observed to have a discrimination index below 0.30. In contrast, 5 had a difficulty index that did not match, and this led to their exclusion from the instrument. Therefore, 45 feasible items were used in the learning achievement test, with their average discrimination index value recorded as 0.50, the difficulty index as 0.60, and the internal consistency coefficient as 0.75.

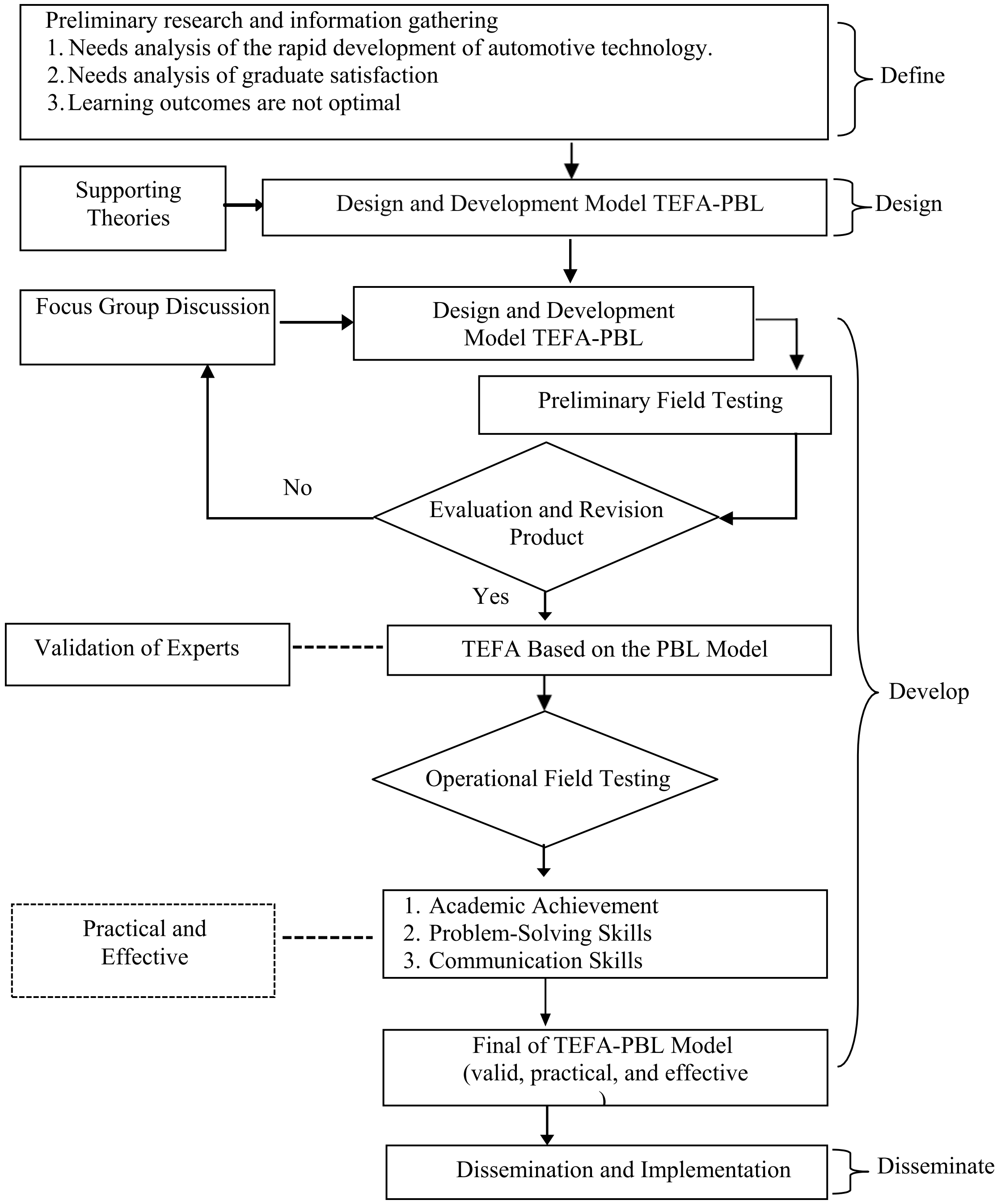

Figure 2. Model Development Stages

Problem-Solving Skills Scale

Problem-solving skills (PBS) were measured by adapting the scale developed by Armor-Thomas and Haynes

(Armour-Thomas & Haynes, 1988) and Masal et al. (2013) using a Likert Scale of 5 alternative options and 30 items under 3 primary indicators of planning, organizing, and evaluating. Cronbach's alpha reliability coefficient of the scale was found to be 0.85, while the value for the sub-variable indicators was 0.85 for planning, 0.75 for organizing, and 0.70 for evaluating.

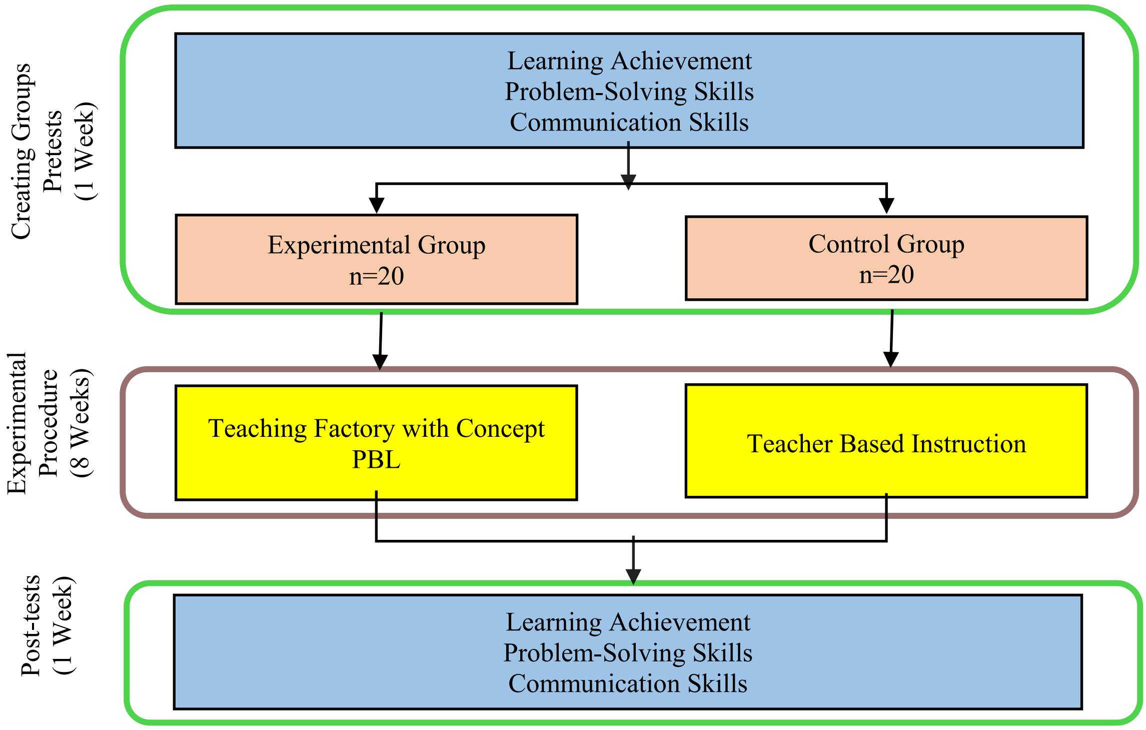

Figure 3. Experimental Design of TEFA-PBL Effectiveness Test Procedure

Communication Skills Scale

Communication skills were measured by adapting the scale developed by Owen & Bugay (Owen & Bugay, 2014) using a Likert Scale with 5 options and 30 question items. The Cronbach's alpha reliability coefficient of the scale was recorded to be 0.79. In contrast, the value for the 4 leading indicators, including communication principles (basic skills), active listening and non-verbal communication, self-expression, and willingness to communicate, was recorded to be 0.70, 0.70, 0.60, and 0.70, respectively.

Result

Product Development Stage

The instrument used to test the TEFA-PBL model framework was adapted from the components of the learning model development by Joyce (Joyce et al., 2015), while the procedure for the development of the model was in line with the stages used in Van den Akker (Van den Akker, 2013). Further details on the instrument component used to develop the model are presented in Table 1.

Table 1. Instrument Components for Developing TEFA-PBL Model

No	Learning Model Components	Descriptions
1	Supporting Theories	Constructivism theory; TEFA syntaxes; PBL syntaxes; Cognitive Theory and Information Processing; Vygotsky's Theory; problem-solving skills components; and
2	Model Concepts and Principles	Syntaxes integration of TEFA-PBL models is conducted by paying attention to the components of learning achievement, problem-solving, and communication skills.
3	Syntax Model of TEFA-PBL	(a) Troubleshooting the problem, (b) organizing the order, (c) Collaborative problem solving, (d) executing order, (e) quality control, (f) Presentation and discussion, (g)
4	Social system	The occurrence of interaction in class, when exchanging opinions between students in solving a problem, students who understand better will assist students who have difficulties in the form of instructions on how to solve the problem
5	Support system	Learning model books, Instructor manual, students manual, module of learning, student worksheets, and assessment
6	Reaction Principles	The lecturer acts as a guide or facilitator. Lecturers must always pay attention to all students in the class so that when students need guidance, the lecturer can directly guide these
7	Instructional Impact	Improve student achievement (cognitive, affective, and psychomotor)
8	Nurturant Impact	Improve Problem-solving and Communication Skills

Content Validity of TEFA-PBL Model Components

The expert validation showed that the model has suitable components of the TEFA-PBL for automotive vocational learning with a pattern to diagnose problems in motor vehicles. The model syntax provides students with a learning experience by collaboratively improving their problem-solving and communication skills. This statement infers that it was able to develop the students' knowledge collectively through multi-directional interactions, as indicated by the students' problem-solving reports, presentations, and good discussions in and outside the group and with their lecturers in the classroom.

In other words, the model is appropriate for improving problem-solving, critical thinking, communication, and collaborative skills, considered basic and global skills of the 21st century. Moreover, the validator provided some recommendations to improve the form of the TEFA-PBL problems given to the students to ensure they are authentic, recent, full of meaning and concepts, and unstructured. It is necessary to form the students' knowledge collaboratively from deductive thinking and prioritize inductive thinking. The validation of each component showed that the TEFA-PBL model has an outstanding value and is considered suitable for learning.

Table 2. Expert Validation Results of the Components of the TEFA-PBL Model

No	Validation Components	V1	V2	V3	V4	V5	Average	Criteria
1	Supporting Theory	3.5	4.0	4.0	4.0	4.0	3.7	Very good
2	Model Concepts and Principles	4.0	4.0	4.0	4.0	3.5	3.7	Very Good
3	Syntax Model of TEFA-PBL	4.0	4.0	4.0	4.0	4.0	4.0	Very good
4	Principle of Reaction	4.0	4.0	4.0	4.0	4.0	4.0	Very good
5	Support System	4.0	4.0	4.0	3.7	4.0	3.7	Very good
6	Social System	4.0	4.0	4.0	4.0	3.7	3.7	Very good
7	Instructional Impact	3.7	4.0	4.0	4.0	4.0	3.7	Very good
8	Nurturant Impact	4.0	4.0	4.0	4.0	4.0	4.0	Very good

Quantitative and qualitative data were analyzed in this research, with the quantitative analysis conducted through expert validation scores on the instrument items. In contrast, qualitative analysis was applied to the data criticized and suggested by experts. It is important to note that the TEFA-PBL model validity test was conducted internally by 3 experts in learning design, and the results were calculated through means of the average score of each instrument component based on a rating scale of 4 for very good, 3 for good, 2 bad, and 1 very bad.

Based on the average validator score, the model was considered feasible and practical to use in this research, as indicated by its "good" conversion. Moreover, the construct validity of the TEFA-PBL Model Syntax with 6 syntax steps and 49 indicators, as indicated in Table 3, was determined using Confirmatory Factor Analysis (CFA), after which all the constructs were categorized based on the criteria for goodness-of-fit to determine their classification as either fit or valid. The findings showed that all syntax and indicators fulfilled the criteria of Stevens (2009:357) and Mayers (2013:870), which require goodness-of-fit models with (/df) < 2, thereby indicating the model is fit.

Table 3. Recapitulation of the Construct Validity of TEFA-PBL Learning Model Syntaxes

NO	Syntax of Model	P-value > 0,05	RSME < 0,05	Chi Square > 0	$\frac{x^2}{df} <$ $2\frac{x^2}{df} < 2$	Correlation index	Criteria
1	Troubleshooting the problem	0,34858	0,078	14,44	1,103	≥ 0,30	Fit/Valid
2	Organizing the order	0,87454	0,000	0,4	0,168	≥ 0,30	Fit/Valid
3	Collaborative problem solving	0,42535	0,093	11,32	1,447	≥ 0,30	Fit/Valid
4	Execute order	0,06944	0,159	30,56	1,328	≥ 0,30	Fit/Valid
5	Quality control	0,63828	0,087	18,58	1,029	≥ 0,30	Fit/Valid
6	Presentation and discussion	0,06461	0,192	20,74	1,624	≥ 0,30	Fit/Valid
7	Assessment	0,02541	0,278	22,21	1,187	≥ 0,30	Fit/Valid
8	Syntax Model of TEFA-PBL	0,81342	0,00	3,97	1,323	≥ 0,30	Fit/Valid

TEFA-PBL Learning Model Practicality

The practicality of the TEFA-PBL learning model and its support system was tested, and the results obtained based on the assessment and observations of the lecturers, practitioners from industry, and students are presented in Table 4. The instrument used includes practical aspects such as attractiveness, ease of use, difficulty level of implementation, reliability, time adequacy, and functionality, and the test showed that the model and its support system are in the very practical category. It was indicated by an average P-value (mean) of 4.55 or a Mean of 91.52%, which indicates "very practical."

Table 4. Practicality Test for TEFA-PBL Model and Supporting System

TEFA-PBL model practicality test	Average score	Achievement (%)	Category
Practicality of the Syntax Model			
Lecturer response	4.70	94.00	Very practical
Student response	4.60	92.00	Very practical
The practicality of Model Book			
Lecturer response	4.59	91.80	Very practical
Student response	4.64	92.80	Very practical
Practicality of Lectures Manual			
Lecturer response	4.63	92.60	Very practical
Student response	4.68	93.60	Very practical
The Practicality of Students Manual			
Lecturer response	4.56	91.29	Very practical
Student response	4.48	89.60	Very practical
Practicality of Student Worksheets			
Lecturer response	4.77	95.40	Very practical
Student response	4.42	88.40	Very practical

Discussion

The Impact of TEFA-PBL on Learning Achievement

Table 5 shows the difference in pretest and post-test scores for learning achievement between the control and experimental classes after ten weeks of applying the TEFA-PBL model. In this experiment, the number of students in each class was 20 research subjects. The results showed that students' learning achievement in the experimental group was significantly higher than that of students in the control group. These results support the findings of other studies that show that the application of the TEFA model, supported by the application of the PBL model, significantly affects student achievement (Virtanen & Rasi, 2017). Furthermore, research shows a significant effect of technology-supported PBL on student achievement (Virtanen & Rasi, 2017; Aslan & Duruhan, 2019). Therefore, the learning achievement of experimental class students treated with the TEFA-PBL learning model was significantly higher than the control class, which used the teacher-based instruction model.

Table 5. Pretest and Post-test Scores Learning Achievement

Variable	Control Class		Experimental Class	
	Pretest Score	Post-test Score	Pretest Score	Post-test Score
Valid	20.00	20	20	20
Missing	0	0	0	0
Interquartile Range	9.25	14.90	11.03	10.75
Mean	52.95	78.73	52.03	88.69
Median	53.00	66.00	53.00	83.00
5% Trimmed Mean	51.14	61.78	51.25	83.27
Variance	83.14	88.78	51.47	51.56
Standard Deviation	8.98	8.62	7.45	7.56
Range	29.35	27.75	28.25	24.50
Minimum	36.40	60.25	36.75	74.50
Maximum	68.75	88.00	67.00	99.00
Skewness	-.315	-.046	-.271	0.13

The TEFA-PBL learning model was reported to have the capacity to serve as a learning guide to accommodate the activities of lecturers and students toward improving learning achievement in higher education (Liu et al., 2019; Valentine et al., 2017). It was also discovered that the achievement of the appropriate skill could be optimized in this model by presenting real and inductive-deductive unstructured problems (Moust et al., 2021; Syed et al., 2021; Zein et al., 2022). Moreover, the model produced a syntactic matrix for lecturers and students with components focused on developing problem-solving, communication, and collaborative skills and achieving the learning objectives. Several research studies have analyzed these components from the perspective of experts with those associated with problem-solving skills observed to include planning, organizing, evaluating possible strategies, acting on strategies, viewing and returning, and evaluating the effects of the activities (Aslan & Duruhan, 2019; Wong, 2017a). Meanwhile, those related to communication skills include communication principles and basic skills, self-expression, active listening, non-verbal communication, and willingness to communicate (Barker, 2019; Owen & Bugay, 2014; Surya et al., 2018).

The Impact of TEFA-PBL on Problem-Solving Skills

The results showed that the students have better problem-solving skills for all indicators than those who studied using teacher-based instruction after 10 weeks of implementing the TEFA-PBL learning model. This statement implies that the model effectively improves the student's ability to solve problems in automotive vocational learning. Moreover, the independent t-test conducted showed that the significance value of the problem-solving skills between the control and experimental classes was less than 0.05, and this indicates there was a significant difference between this variable for those in the experimental class "learning using TEFA-PBL" and the control class using "Teacher-based instructions." The model improved the students' problem-solving skills, as shown in the planning, organizing, and evaluating indicators, thereby increasing their academic achievement.

The study results revealed that the problem-solving skills of students in the experimental group developed significantly compared to those of students in the control group. These results are consistent with similar studies in the literature (Valentine et al., 2017; Helmi et al., 2017; Phungsuk et al., 2017). However, some studies report that PBL activities do not significantly improve problem-solving skills. Some of the research results, including Cevik et al. (2015), Aslan (2021), and Maksum et al. (2019), have investigated the effect of PBL activities on participants' problem-solving skills and reported that they found no significant differences. In addition, in a literature review, it was found that collaborative problem-solving practices are more beneficial than individual practices (Reidy, 2001; Belousov, 2020) and that the PBL approach is a practical approach for developing student problem-solving skills (Phungsuk., 2017; Yuberti et al., 2021; Ting et al., 2021).

Several previous experimental studies regarding implementing the TEFA-PBL model in engineering learning resulted in positive findings on improving student problem-solving skills (McLoone et al., 2016; Foster et al., 2017). In this study, students using the TEFA-PBL model had a higher capacity for problem-solving skills than in teacher-based instruction. Previous studies conducted by various researchers showed similar results in vocational education (Budak et al., 2018; Jose, 2016; Helmi et al., 2017; Kadir, 2016). In addition, these findings align with the goals of TEFA and PBL to increase competence in solving unstructured problems, as Savin-Baden (2016) stated.

Problem-solving skills are one of the Industrial Revolution 4.0 skills for new-millennium individuals (Mazorodze & Reiss, 2019), so the TEFA-PBL model development research results are very important. As stated by Larson (2012), problem-solving includes many cognitive processes, from identifying the problem to proposing a solution. In this context, TEFA-PBL applied in the experimental class environment has an effect that can increase students' problem-solving skills. Based on the results of the study, it shows that TEFA-PBL is a good alternative for developing students' problem-solving skills. According to Pangeni and Karki (2021), improving and developing problem-solving skills is one of the essential goals of modern education in the future. The importance of increasing student problem-solving skills in many fields, ranging from engineering to medicine, is highly expected in everyday learning activities (Burkholder et al., 2021).

The Impact of TEFA-PBL on Communication Skills

The TEFA-PBL learning model effectively improved students' communication skills in automotive vocational learning after 10 weeks of implementation. The independent t-test also showed that the significance value of this variable between the control and experimental classes is smaller than 0.05, which means there are differences in the learning outcomes from the experimental class, which used "TEFA-PBL" and the control class with "teacher-based instruction." These differences were associated with the ability of the TEFA-PBL to motivate students to engage in two-way communication actively. At the same time, the teacher-based instruction methods reduce the students' confidence when communicating since they learn from several different places and instructors. These results were discovered to be in line with the theories put forward in previous studies (Virtanen & Rasi, 2017), which show communication as one of the prerequisites to developing students' behavioral skills (Elzomor et al., 2018; Jdaitawi, 2020; Kumar & Lata, 2015). Moreover, Barker (2019) reported that communication, working memory, working in a social environment, and attitudes promoting student communication are operational.

Automotive engineering students learn to work collaboratively in communities, thereby taking on social responsibility. The most significant contribution of TEFA-PBL is that it also helps create better work habits and attitudes towards learning (McConnell et al., 2016; Wallace et al., 2016). Even though students work in groups, they become more independent because they receive fewer instructions from lecturers (Syed et al., 2012; Naslund & Filipenko, 2019). With TEFA-T, students also learn essential skills in higher education, namely communication skills; this is reflected in the activities in the TEFA-PBL learning model in the last syntax, namely presentation and discussion. Students learn more than just finding answers to a given problem; TEFA-PBL allows them to broaden their minds and think beyond what they usually do. Students must find answers to the syntax for troubleshooting the problem in groups and complete group assignments using problem-solving skills to produce answers.

This study's results align with research conducted by Farmer and Wilkinson (2018), which states that applying the PBL model in the chemical engineering classroom can improve student communication skills. The more often students practice and communicate with consumers, the better their communication skills will be. Communication Skills are skills for maintaining work relations in the workplace. These skills are needed to build good relationships with others individually and in teams (Dierdorff et al., 2021). Communication Skills are needed to overcome problems arising from work through information sharing or discussion (Aslan, 2021).

In automotive engineering learning, communication skills have a great opportunity to be developed independently by students. For example, communicating actively with consumers who will be served, providing comprehensive information related to the progress of maintenance and repair of motorized vehicles to consumers, communicating with superiors if problems occur with vehicles that cannot be solved, and communicating with colleagues to obtain information about vehicle medical records (Michelle et al., 2020) An intermediate expert in Automotive Engineering is expected to have practical communication skills in carrying out his duties as an intermediate expert. This ability is assessed not only through verbal communication but also through non-verbal communication. Someone is expected to have sensitivity in responding to communication, for example, by giving an expression of nodding his head when working conditions make it impossible to speak or by giving specific cues through his eyes if there is a communication that is confidential but must still be communicated without the knowledge of other people around him. It is also expected to have a high sense of empathy to respond to conditions that will occur.

Conclusion

This research has produced a six-step learning model, namely (1) troubleshooting the problem; (2) organizing the order; (3) collaborative problem solving; (4) executing orders; (5) quality control; (6) presentation and discussion; and (7) assessment, abbreviated as the TEFA-PBL model. The novelty value in this study is the PBL concept in implementing the Teaching Factory, a characteristic of automotive vocational learning. Based on theoretical studies, empirical tests, and expert advice, implementing the TEFA-PBL model constructs the fundamental and global skills needed in the era of the ongoing industrial revolution 4.0: learning achievement, problem-solving skills, communication skills, and collaborative skills. In implementing the TEFA-PBL model, students build knowledge inductively and deductively, as well as through learning experiences in one-way interactions, personal interactions, and multi-directional learning interactions. The TEFA-PBL Learning Model and product development support results are stated to be statistically valid and practical. The results of the study stated that the TEFA-PBL learning model was declared valid, both from the aspect of content validity and construct validity. The results of this study indicate that implementing the TEFA-PBL learning model is effective and significantly improves aspects of learning achievement, problem-solving skills, Communication Skills, and student collaborative skills in automotive vocational learning.

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