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Pattern Transformations: Supporting Learning of Symbolic Representations Among TVET Trainees

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Abstract: Symbolic representations are a form of language that is routinely used in technical communications. Trainees in Technical and Vocational Education (TVE) are thus, expected to master symbolic representations concurrently with skills acquisition. Electrical circuit diagram is an example of symbolic representations in use to communicate information on the components and working concepts of an electrical circuit. Mastering symbolic representations in circuit diagram however, can be challenge to some which often lead to miscommunications and poor job performance. Problems are further compounded when trainees need to learn symbols associated with abstract concepts. Inability to master the "symbols language" if remain unchallenged will impact subsequent learning. Appropriately designed instructional materials to address learning of symbolic representations are thus crucial. The aim of this paper is to assess the efficacy of two instructional materials for learning symbolic representations and electrical concepts. A quasi-experimental study with three groups of TVE trainees participated in this study. One group used the existing learning materials (control) while the other two groups used specifically designed pattern transformation materials that are available in two media, print-based and video-based materials. Overall, both experimental groups achieved greater learning on symbolic representations and concepts compared to the control group. Equivalent status was also observed among the experimental groups. This indicates that pattern transformation materials irrespective of media used can be effective at learning symbolic representations in electrical related content.

Keywords: Pattern transformation, symbolic learning, electrical circuit diagram, learning material

1. Introduction

The ability to read and translate non-verbal (and non-textual) instructional materials (such as symbols and diagrams) is important in the technical fields such as engineering, electronics, and architecture (Egan & Schwartz, 1979), mathematics (Bennett, Inglis, & Gilmore, 2019), and the sciences (Taber, 2009). In engineering, technical drawing serves as communication tools between designers and manufacturers or clients (Burvill, Field, Abdullah, & Alias, 2016). In Chemical Education, contents are typically represented using a specific symbol system to describe chemical

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compositions and interactions, while learners often have difficulties in interpreting these symbols (Taber, 2009). Poor ability in understanding such materials can cause misinterpretations and misconceptions (Ott, Brünken, Vogel, & Malone, 2018), and if not addressed during education and training will lead to low job competence. Even in daily life, symbols are used in communication (Sinha, 2004). The reality is, misinterpretations have been observed across disciplines from pure sciences such as chemistry (Taber, 2009) and physics to applied sciences such as mechanical engineering (van der Meij, 2007). Thus, there is a strong need in enhancing the skills in reading and translating of symbolic representations among learners of all disciplines.

Learning with pictures, graphs, diagrams, and symbol may contribute to multiple difficulties if the teachers or instructors fail to provide learners with good guidance (Vogt, 2002). Difficulties arise due to the nature of the relationship between a symbol and its referent (Reilly, Peelle, Garcia, & Crutch, 2016). According to Vogt (2002), one symbol or sign represents a relationship triangle between its meaning, form and referent and active construction and use are necessary to arrive at the correct conclusion of the relationship. Taber (2009) further suggest that learning with symbols is difficult due to lack of familiarity with the symbols, the need to have a theoretical understanding of the symbolic representations, and the use of a range of symbols in multiple applications. Other scholar suggest that there are at least four possible factors that contribute to the difficulties in learning with symbols; firstly, a symbol does not have meaning cognitive wise (Isaacson & Lloyd, 2013). Secondly, a simple symbol is used to represent a complex concept; thirdly, each symbol has its method of representation (Twissell, 2014) and fourthly, there is no physical connection between the real object with the symbol (Hoffmann, 2007). Furthermore, there is no logical or meaningful basis for mental guessing the conformation of the symbol being generated (Isaacson & Lloyd, 2008).

In the Technical and Vocational Education and Training (TVET) students are expected to deal with many forms of non-textual and non-verbal instructional materials such as pictures, graphs, diagrams and symbols (Billett, 2016b). Students need to interpret the content into meaningful meaning which proceeds to become cognitive content (Agra et al., 2019). Based on the relationship triangle proposed by Vogt (2002), an electrical circuit diagram, for example, can be easily misinterpreted by a student due to the unfamiliar symbols used in the circuit (Finkelstein et al., 2005), in particular if rote learning is being routinely emphasized. Grasping the relationship triangle of a symbol requires meaningful learning and absence of meaningful learning of symbolic representations can occur if teachers or instructors fail to use appropriate methods for teaching symbolic representations. Meaningful learning can occur if students can relate the new knowledge to what they already know. Absence of meaningful learning can lead to poor construction of new knowledge which is important in problem-solving skills development. Thus, Billett (2016) suggests that the widely used problem-solving method can only be successful if learners can capture meaningful knowledge from the learning content. Specific to electrical engineering-related courses, electrical circuits is often associated with students' misinterpretations or misconceptions (Li & Singh, 2016; Timmermann & Kautz, 2015; Mitros et al., 2013; Taşlıdere, 2013; Başer & Geban, 2007). Therefore, improving understanding of symbolic representation is important and meaningful learning is the key.

1.1 Teaching Symbolic Representations in TVET: Theory and Practice

According to the cognitive information processing theory, visual representation such as images, symbols and diagram are encoded as visual stimuli in the phonological short term memory upon repeated exposure (Brandimonte, Hitch, & Bishop, 1992). In TVET, students are expected to undergo repeated trial and error of practical hands-on activities to learn a new job skill. Repeated exposure to tasks also promotes learning of procedures which is often required in practical skills development in TVET. Furthermore, a student's belief system can help the encoded stimuli from the repeated exposure stay longer in a students' memory (Turnitsa, Padilla, & Tolk, 2010). However, an inaccurate belief system can lead to misconceptions of the content being learned (Özdemir & Clark, 2007). Therefore, meaningful learning where students' prior belief system is being considered in introducing new information is necessary for successful learning of symbolic representations.

Research has also indicated that learning with graphics (a form of symbolic representation) increases students' motivation to continue learning but does not lead to enhanced learning (Sung & Mayer, 2012). This issue is also an aspect that needs to be addressed when preparing instructional materials for learning symbolic representations. In technical and engineering field, symbolic representation is used as an alternative to textual representation for the faster presentation of abstract information (Twissell, 2014). However, due to the relationship triangle between meaning, form and referent that one symbol represents (Vogt, 2002), students with lower cognitive ability often have difficulties in reading and interpreting symbolic representations. Students with lower cognitive ability, however, are typical of TVET enrollees in the engineering-related fields raising more concern to address teaching and learning of symbolic representations. The aim of this paper is to report of a study investigating the effect of newly designed materials on learning of symbolic representations.

1.2 Media Selection: Printed or Multimedia Materials?

Despite the advance in learning technology, printed learning materials are still used in delivering content. Such practice is an advantage to students with little domain knowledge or low spatial abilities as they often have difficulties comprehending materials using multimedia displays (Hegarty, 2005). Presentation modes of printed materials, however, may play a role in learning as shown by Reisslein, Moreno, and Ozogul (2010), who found that students who were using printed materials with multiple representations learned better compared to their counterpart who was using a single representation of the same information. A recent study further indicates that combined print and multimedia materials are helping students in reducing their misconceptions (Taşlıdere, 2013). Taşlıdere (2013) found that cartoon worksheet and simulation method can decrease misconceptions on a direct current in the electric circuit topic.

Further support for multimedia learning is shown by Nwineh & Okwelle (2018) who found students who are taught electrical installation using computer simulation demonstrated better performance than students who were taught using the face to face demonstration method. The superior results of the multimedia method could be due to the repeatability of the digital “demonstrations” since repeated exposure has been shown to improve learning as suggested by Turnitsa, Padilla, & Tolk (2010). Thus, both delivery modes, print and multimedia have their own advantages and disadvantages. In other words, there is no agreement on the better mode of delivery between print-based and technology-based learning materials. Thus, the aim of this study is to investigate the effect of a patter transformation strategy - in print-based media and video media – which are examples of meaningful learning strategy in practice -on conceptual and procedural learning of circuit diagrams.

2. Methods

A pre and post-test quasi-experimental design was adopted for the study, with control and experimental group.

2.1 Participants

Participants were three cohorts of third semester trainees from the Certificate of Air Conditioning program in one skills training centre in Malaysia. The first cohort (semester 1 2016) in the experimental group 1 (15 trainees) received printed-based material, the second cohort in the experimental group 2 (25 trainees) received to video-based material and the third cohort was assigned to the control group (24 trainees) to receive traditional training.

2.2 Intervention materials: Design and Development

New materials were developed based on the principle of the best way to learn symbolic representations. Symbolic representation is best to learn when the relationship between the associated symbols and its referent are putting together concurrently (Isaacson & Lloyd, 2008). To achieve concurrent learning of object and symbol, new learning materials were developed in two media – print-based and video-based - by undertaking the following steps; Designing transformation pattern; Designing and developing learning materials.

2.2.1 Designing Transformation Patterns

i. Taking photos of electrical components
Using DSLR camera, each electrical component in a vehicle air conditioning system was captured. Figure 1 shows one example of an electrical component (resistor).

Fig. 1 - Example of resistor.

ii. Printing the photo and tracing each photo of an electrical component using free-hand sketching and converting it into wired picture.

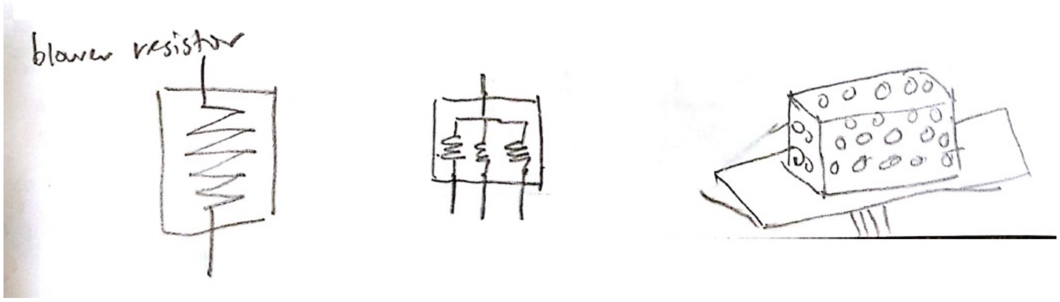


Fig. 2 - Hand drawing of the component.

iii. Digitizing the hand sketches and creating multiple brief wired pictures. These brief wired pictures are called patterns.

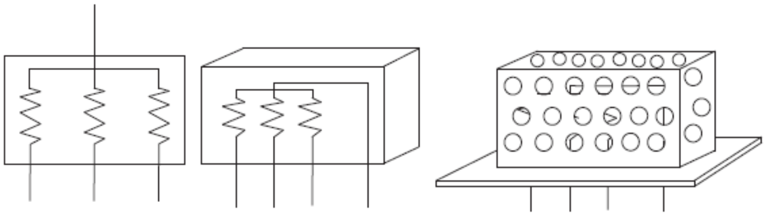


Fig. 3 - Several patterns for blower resistor.

iv. Drawing the symbol.

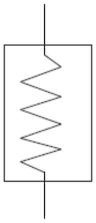


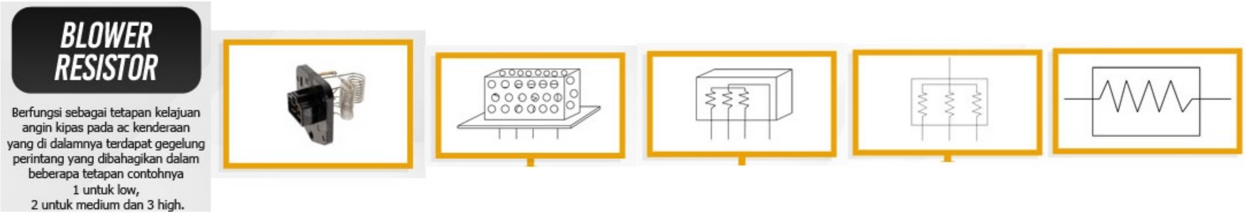
Fig. 4 - Symbol of a blower resistor.

2.2.2 Designing and Developing Learning Materials

After completing all of the above steps, pictures of each electrical component were compiled in one pdf file. Then, all pdf files were sent to instructors for verifications - to verify the patterns and symbols. After receiving instructors' consent, the design process of the learning materials began.

The completed new learning materials were developed in two media; printed-based and video-based medium, where each learning kit contained information on 10 electrical components for a vehicle air conditioning system. The materials present the picture of a component followed by patterns and symbols of a circuit diagram. Descriptions of the function of each of the electrical components were also given alongside in addition to a circuit diagram with illustration on electrical current flow.

The printed-based version was designed in a form of a pamphlet in which all of the basic components were embedded into one piece of paper. Figure 5 shows an example of the learning materials for a component. Meanwhile the video version was developed in in 11 videos separately. All videos were designed using Powtoon Enterprise. The software is available online through yearly subscription. The video-based learning materials were disseminated to trainees via mobile phones using the "WhatsApp" group application. An example of the video-based material is shown in Figure 6.



Berfungsi sebagai tetapan kelajuan angin kipas pada ac kenderaan yang di dalamnya terdapat gegelung perintang yang dibahagikan dalam beberapa tetapan contohnya
1 untuk low,
2 untuk medium dan 3 high.

Fig. 5 - Design example of the printed-based material.

Fig. 6 - Three screen capture of the video-based material.

2.3 Research Procedures

The research procedure is as shown in Table 1. The duration of study was eight weeks with the first week on paper and pen pre-test, briefing and distributing of the learning materials. Actual learning session began on the second week.

Table 1 - Scheduling for pretesting, T&L session and post testing.

No	Week	Activities
1	Week 1	Pre-test
2	Week 2	Teaching and learning session with learning material or used conventional method
3	Week 3	T&L session
4	Week 4	T&L session
5	Week 5	T&L session
6	Week 6	T&L session
7	Week 7	T&L session
8	Week 8	Post-test and Questionnaire distribution

The pre-test and post-test contains the same questions which include questions about naming the symbols and describing the functions of associated components. There were also questions on procedural knowledge based on the circuit diagram. A questionnaire was then administered to elicit information regarding participants' satisfaction towards using the new learning materials.

3. Results

One-way analysis of covariance (ANCOVA) was conducted to compare the mean differences between performances of the three groups. The post-test results show that the printed group had the highest mean (79.96), while the control group had in the lowest (refer to Table 2).

Table 2 - Observed means and standard deviations for means on post test.

Mode of delivery	n	Mean	SD
Printed-based	15	79.960	9.210
Video-based	25	74.219	9.110
Control	24	62.862	11.762

Result of the ANCOVA revealed a statistically significant main effect for applying new learning material, F (2, 60) = 13.668, *p* = 0.000 as show in Table 3. Participants who were using printed-based and video-based outperformed the control group.

Table 3 - Analysis of covariance for achievement post-test as a function of mode of delivery, using achievement pre-test as a covariate.

	df	Ms	F	P	eta^2
Pre-test	1	1005.608	11.266	.001	.158
Mode of delivery	2	1219.995	13.668	.000	.313
Error	60	89.261			

The post hoc test for the mode of delivery variable was tested at the pre-established alpha level of .05. The print-based condition and the video-based condition were compared to the control condition revealing a mean difference of 15.648 and 10.018 indicating that there is a statistically significant difference between modes of delivery methods as depicted in Table 4.

Table 4 - Post hoc test results by training condition.

Mode of delivery (I)	Mode of delivery (J)	Mean Difference (I-J)	Sig.
Printed	Video	5.629	.073
	Control	15.648^*	.000
Video	Printed	-5.629	.073
	Control	10.018^*	.001
Control	Printed	-15.648^*	.000
	Video	-10.018^*	.001

Figure 7 illustrates the trend analysis of observed mean achievement post-test performance scores based on mode of delivery. Difference between printed-based and video-based was 5 points, while between video-based and control group was more than 17 points. Its show that new learning material gave an effective learning to trainees.

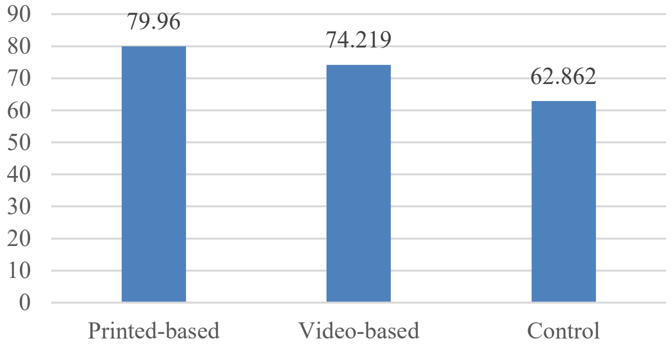


Fig. 7 - Mean achievement post-test performance based on mode of delivery

4. Findings and Discussion

The engineering and technical sectors need knowledge workers who have a strong foundation in symbolic representations. Thus, technical and vocational students must have the ability to recognize not only symbols of referents but also their functions and system operations. In the learning processes, students are expected to learn new symbols and referents which are constraint by conventions but may also be exposed to opportunities to interpret symbols based on their perspectives (DeLucia, 1991). The exploitation of symbols in the form of image and concept models may enhance the learning of abstract concepts (Chen, Hong, Sung, & Chang, 2011). Thus, to teach symbolic representations witch themselves are also images may need other images to as teaching aids for effective teaching and learning.

The intervention of new learning materials was tried to enhance the learning of symbolic representations using a combination of real pictures of the represented component and associated symbols that were transformed through a pattern transformation process. The findings indicate that the pattern transformation process is indeed a good strategy to enhance the learning of symbolic representations. The decision for the pattern transformation is an enhancement of the ideas proposed by Johnson, Butcher, Ozogul, & Reisslein (2014) who suggest that symbols are best learned concurrently with their referents. The learning materials were also decided after contemplating on findings from Kollöffel & de Jong (2013) who found that a combination of text-book and practical lesson did not provide an optimal condition for students in understanding an electrical circuit.

The textbook and practical lesson is the typical traditional method used in learning circuit diagrams, though. Integrating circuit diagram with the equation show better result on student cognitive understanding towards content (Ozogul, Johnson, Moreno, & Reisslein, 2012). A study by Ortega-Alvarez, Sanchez, & Magana (2018) show that learners have a better conceptual understanding towards electrical circuit content after exposed to multi-representational teaching methods. Supported by Kapici, Akcay, and de Jong (2019), learners who exposed to several types of techniques in learning electrical circuit show a better achievement compared to the group who only exposed to one technique. Also, circuit simulator is one of good exemplar of teaching aid for novice to learn circuit diagram (Cubells-Beltrán & Reig, 2018). However, developing a circuit simulator needs experts, effort and time. Chi (2005) proposed that instructional intervention needs to focus on helping a student to build such a schema first to overcome misconceived concepts. Thus, the pattern transformation used in this study in addition to function descriptions and circuit diagram (with current flow indication) seems to represent the ideal learning materials for learning symbolic representations meaningfully.

5. Conclusion

The utility of the new learning materials is supported by the data, which shows greater achievement in students' conceptual and procedural knowledge of the experimental group compared to the control group. Interestingly, students using print-based materials and video-based materials do not differ in their achievements which support the conclusion that media is not the key that influences learning. The key is the way learning needs are addressed through an understanding of how learning of symbolic representations (in this study) and learning, in general, can be enhanced and subsequent application of instructional design principles, such as the case in this study. Therefore, an appropriate design of learning experiences is a necessity to enhance student learning of symbolic representations in particular and learning in general. In conclusion, meaningful learning through a combination of pattern transformation from object to symbols, function descriptions and schematic diagrams with flow direction help students learning symbolic representations that supports conceptual and procedural understanding of electrical circuits.

6. Future Research

Misinterpretations of symbolic representations are common occurrences among TVET trainees who tend to come from disadvantaged groups with low socioeconomic status, lower cognitive ability and lower learning motivations. Application of the current pattern transformation strategy can be tested on other topics that are heavy on symbolic representations to generate more data on its applicability. Such research could generate greater understanding on the relationship between specific symbols and their referents, as well as, on identifying suitable delivery media such as online medium to deliver content.

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