Assessment of electrical engineering students' creative thinking skills in PLC programming

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ABSTRACT: The purpose of this study was to develop an instrument to test the creative thinking skills of electrical engineering students in programmable logic controller (PLC) programming. The development of creative thinking test instruments is based on six elements that are: intellectual skills, knowledge, thinking styles, creative functions, motivation and the environment. The test instrument for creative thinking skills in PLC programming is in the form of observation items and performance test scores, and was developed based on Bloom's taxonomy in the psychomotor domain. The instrument was tested on 80 students. Measurement data were analysed using the partial credit model. The results of the instrument validation were very good, that is obtaining an average Likert index value of 99.12%. The results of the data analysis show that there are 16 items that are declared fit within the model based on the criteria in the IMS and OMS values. In conclusion, the instrument developed for testing students' creative thinking skills in PLC programming is suitable for that assessment.

INTRODUCTION

Every company requires and demands knowledgeable and skilled graduates with suitable competencies, which are often referred to as the four C's, viz critical thinking, communication, collaboration, and creativity and innovation [1]. The National Education Association (NEA), the largest labour union in the USA has promoted this idea to its members, who are mostly educators at all levels of schooling. In the 21st Century, there is a lot of pressure on teachers to aid the development of these four competencies. Creative thinking is closely related to creativity, because creativity can be understood as the result of one's creative thinking process [2][3]. Critical and creative thinking skills as part of the competencies required for programmable logic controller PLC programming are indispensable for a 21st-Century teacher.

In the current teaching environment, it is necessary to enable students to be creative, including their learning process. To improve critical and creative thinking skills in PLC programming, appropriate media are required, such as a training kit equipped with a PLC module. Several industrial process control prototypes with PLCs have been developed with the aim of helping students gain practical experience [4]. The experimental device and the PLC module make the learning process easier and safer [5]. PLC kits have also been developed for factories; for example, *to track closely the production, reduce the manual control and efficiently monitor the bottling process of small beverage* plant by implementing Industry 4.0 [6]. The development of criteria for measuring creativity or imagination in student work should not be guided by the level of student creative products, but by evidence of students' use of creative thinking and skills [7]. The Torrance test is often applied to determine a person's creative thinking ability, which consists of verbal and figural forms [8].

According to investment theory, creativity requires six different, but interrelated resources that are:

1) intellectual skills;
2) knowledge;
3) thinking styles;
4) creative functions;
5) motivation;
6) the environment [9].

Although there are individual differences in the level of these resources, often a decision to use these resources is more important than individual differences [9].

In the pedagogical process, it is inevitable to seek methods and procedures that allow interactive transmission of knowledge within the teaching structure of the faculty [10]. To gauge the creative thinking skills of electrical engineering students in PLC programming at the State University of Surabaya (UNESA), Indonesia, a performance appraisal instrument has been created based on a review of Bloom's taxonomy, and particularly in regard to the psychomotor domain [11].

METHODOLOGY

The type of research undertaken at the UNESA includes research and development (R&D) [12]. The development part refers to a test instrument for assessing creative thinking skills. According to Gall et al this type of research can be divided into the following four stages: defining, drafting design, developing and implementing [12]. The defining stage includes two phases; namely, 1) field studies, to obtain information on the form and type of PLC assessment instruments already used; and 2) laboratory infrastructure assessment, including the PLC learning process. The literature review was mainly focused on references regarding the criteria for developing creative thinking skills and the indicators of creative thinking skills.

Educational product design typically begins with compiling a matrix, questions, answer keys, and validating the design by experts in educational research, creative thinking skills and PLC programming. After validation, the assessment instrument had been revised several times and improved, so that it was feasible to begin testing. The instrument's improvement and refinement was carried out with direction, guidance and input from the validator.

The development stage was carried out by testing the instrument's quality through the questions' validity and reliability, including 80 students who studied PLC in the departments of electrical engineering, at the UNESA and the University of Hang Tuah Surabaya, both in Indonesia. The instrument was declared valid by the expert group and has a coefficient of reliability and validity in a moderate to high category.

PLC Training Kit

The PLC training kit used in this study is a learning medium in the form of a simulation as outlined by Rusimamto et al [13]. In this context, simulation refers to multimedia that match real processes in the real world. One of the learning strategies is the use of simulation models. It aims to provide a more real learning experience through creating virtual imitations of real-live processes and conditions and without risk. One of the practical exercises carried out is the fluid mixing system exercise shown in Figure 1 [13].

Test Instrument for Creative Thinking Skills Assessment

The PLC programming performance test is a practical observation test for setting fluid mixing processes consisting of 19 observation items which can be seen in Table 1. The performance test is to create a PLC program with the conditions as shown in Figure 1 [13].

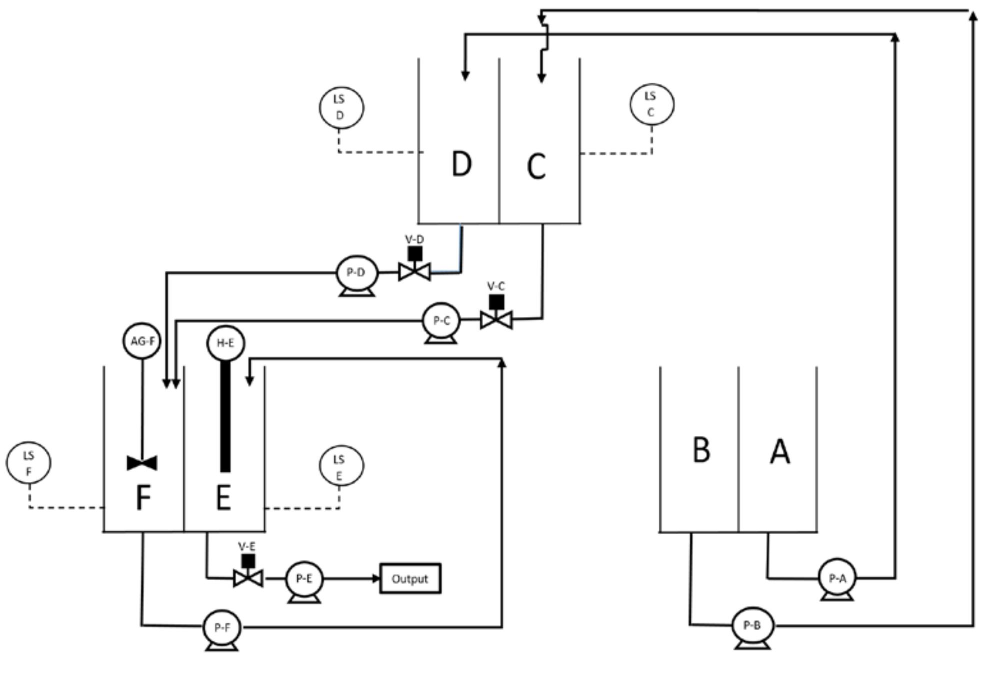

Figure 1: Fluid mixing process [13].

In this study, the test of creative thinking skills has been developed using a performance observation sheet. The test scoring criteria are made up of three score categories. The score is 1, if the student cannot complete each step; the score is 2, if the student completes some of the steps; and the score is 3, if the student completes each step correctly. The observation sheet in Table 1 demonstrates the steps involved in solving the problem, as well as the corresponding score.

Table 1: Observation sheet of creative thinking skills in the fluid mixing process exercise.

No.	Score 1	Score 2	Score 3
1	Cannot describe the philosophy of the fluid mixing control process	Can describe part of the philosophy of the fluid mixing control process	Can describe the philosophy of the fluid mixing control process
2	Cannot draw ladder diagrams using CX-Programmer	Can draw ladder diagrams using CX-Programmer, but many are incorrect	Can correctly draw ladder diagrams using CX-Programmer
3	Unable to analyse ladder diagrams	Can analyse ladder diagrams, but can be wrong on some points	Can correctly analyse the ladder diagram
4	Cannot combine two programs using CX-Programmer	Can combine two programs using CX-Programmer, but not correctly	Can correctly combine two programs using CX-Programmer
5	Cannot apply a program with timer functions using CX-Programmer	Can apply a program with timer functions using CX-Programmer, but not correctly	Can correctly apply a program with timer functions using CX-Programmer
6	Cannot apply the fluid mixing program using CX-Programmer	Can apply the fluid mixing program using CX-Programmer, but not correctly	Is able to correctly apply the fluid mixing program using CX-Programmer
7	Cannot prove that the created program concurs with the instructions	Can prove that the created program concurs with the instructions, but not correctly	Can correctly prove that the created program concurs with the instructions
8	Unable to upload the program from CX-Programmer to the PLC	Can upload the program from CX-Programmer to the PLC, but not correctly	Can properly upload the programs from CX-Programmer to the PLC
9	Cannot properly run programs built into the PLC	Can run programs built into the PLC, but can be wrong on some points	Can properly run programs built into the PLC
10	Unable to assemble a training kit for the fluid mixing setting	Can assemble a training kit for the fluid mixing setting, but many steps go wrong	Can correctly assemble a training kit for the fluid mixing setting
11	Cannot connect the training kit and the PLC	Can connect the training kit and the PLC, but can be wrong on some points	Can properly connect the training kit and the PLC
12	Cannot operate the human-machine interface (HMI) from the fluid mixing setting	Can operate the HMI from the fluid mixing setting, but many steps go wrong	Can properly operate the HMI from the fluid mixing setting
13	Cannot resolve the failure in the fluid mixing control process if it is not in the instructions	Can resolve the failure in the fluid mixing control process if it is not in the instructions, but is often incorrect	Can correctly resolve the failure in the fluid mixing control process, even if it is not in the instructions
14	Unable to complete the work and create a program to control fluid mixing using CX-Programmer and the HMI using the training kit	Can complete the work and create a program to control fluid mixing using CX-Programmer and the HMI using the training kit, but can be wrong on some points	Can successfully complete the work and create a program to control fluid mixing using CX-Programmer and the HMI using the training kit
15	Unable to complete the work and create a program to control fluid mixing using CX-Programmer and the HMI using the training kit in a well-organised manner	Can complete the work and create a program to control fluid mixing using CX-Programmer and the HMI using the training kit, but not in a well-organised manner	Can complete the work and create a program to control fluid mixing using CX-Programmer and the HMI using the training kit in a well-organised manner
16	Cannot do all the work, but creates a program to control fluid mixing using CX-Programmer and the HMI using the training kit quickly and effectively	Can do all the work and create a program to control fluid mixing using CX-Programmer and the HMI using the training kit, but is not fast enough and often incorrect	Can quickly and correctly do all the work and create a program to control fluid mixing using CX-Programmer and the HMI using the training kit
17	Does not use literature from multiple sources to create a program to control fluid mixing	Can use some literature to create a program to control fluid mixing	Can use literature from various sources to create a program to control fluid mixing
18	Unable to communicate, discuss and collaborate with group friends, technicians and lecturers	Can communicate, discuss and collaborate with group friends, technicians and lecturers, but not well	Can communicate, discuss and effectively collaborate with group friends, technicians and lecturers

19	Unable to work and co-operate with groups in regard to fluid mixing control programs, uploading to PLCs and running HMIs with the trainer kit application	Can work with groups, but is not co-operative in regard to fluid mixing control programs, uploading to PLCs and running HMIs with the trainer kit application	Can work with groups and co-operate in regard to fluid mixing control programs, uploading to PLCs and running HMIs with the trainer kit application

Validation of the Creative Thinking Skills Test

The validation of the PLC programming creative thinking skills test was based on an assessment from the validator. The validation results were analysed with a Likert scale and used as a reference in revising performance observation instruments [14]. In the implementation of performance tests, the scoring is done step by step, and the score per item is obtained by adding up the students' scores for each step, and the ability is estimated with the raw score. This scoring model is not necessarily appropriate, because the difficulty level of each step is not taken into account. In addition, the chances of a student providing the right answer based on a particular response are unpredictable.

An alternative approach that can be used is the item response theory with polytomous scoring. This type of scoring refers to test results consisting of two or more values, where the scoring is carried out step by step for each item, taking into account the level of difficulty at each step in solving the item. The highest score is, of course, obtained when the test taker is able to correctly answer the questions until the final step. There are several models that can be used in analysing polytomous items, one of which is the partial credit model (PCM), as has been done by Istiyono et al [15]. All test instruments were declared fit with the PCM.

The PCM, which is a one-parameter logistic model (1-PL model)) assumes that the difference in each item is the same and the level of difficulty in each stage does not need to be sorted [16]. Analysis on the PCM determines the item information function (IIF), test information function (TIF), and the parameter estimation of students' abilities as indicated by the theta parameter value [17]. In the study outlined in this article, instrument testing was carried out on 80 students who attended PLC courses.

The obtained scoring data are then evaluated using the PCM. In this study, the Quest program was used to analyse the PCM. The Quest output can also produce a comparison of the level of difficulty for the participants in regard to each item in the model [18]. The test items used have to concur with the partial credit model and are selected based on the infit mean square (IMS) and outfit mean square (OMS) (outfit mean-square) values. The IMS and OMS statistics are a measure of the degree of conformity between the observed data and the values predicted by the model [19].

RESULTS

The validity results of the fluid mixing performance instrument were analysed using a Likert scale. The average index is 99.12%, which means that the observation instrument has a very good Likert index rating. This result is the average result of all items, so each item of the instrument can be declared fit for use. The calculation results of the response model parameter estimates are shown in Table 2. Table 3 shows the generalised item analysis - statistics. Table 4 includes the interpretation of IMS and OMS values.

Table 2: Response model parameter estimates.

Variables		Estimate	Error^	Unweighted fit			Weighted fit		
	Item			MNSQ	CT	T	MNSQ	CT	T
1	1	-3.103	0.262	0.47	(0.69, 1.31)	-4.2	0.87	(0.55, 1.45)	-0.6
2	2	-2.568	0.248	0.41	(0.69, 1.31)	-4.8	0.72	(0.63, 1.37)	-1.6
3	3	-2.229	0.24	1.2	(0.69, 1.31)	1.3	0.77	(0.66, 1.34)	-1.4
4	4	-1.138	0.222	1.16	(0.69, 1.31)	1	1	(0.73, 1.27)	0
5	5	-0.515	0.218	0.73	(0.69, 1.31)	-1.8	0.87	(0.74, 1.26)	-1
6	6	0.973	0.227	0.47	(0.69, 1.31)	-4.2	0.69	(0.71, 1.29)	-2.3
7	7	1.058	0.228	0.46	(0.69, 1.31)	-4.2	0.68	(0.70, 1.30)	-2.3
8	8	0.968	0.227	1.1	(0.69, 1.31)	0.6	1.2	(0.71, 1.29)	1.3
9	9	1.142	0.23	1.15	(0.69, 1.31)	1	1.03	(0.70, 1.30)	0.3
10	10	1.049	0.228	1.4	(0.69, 1.31)	2.3	1.26	(0.70, 1.30)	1.6
11	11	1.517	0.237	2.76	(0.69, 1.31)	7.7	1.61	(0.67, 1.33)	3.1
12	12	2.634	0.267	0.56	(0.69, 1.31)	-3.3	1	(0.52, 1.48)	0.1
13	13	2.984	0.278	0.39	(0.69, 1.31)	-5	0.88	(0.44, 1.56)	-0.4
14	14	1.61	0.24	0.43	(0.69, 1.31)	-4.6	0.67	(0.66, 1.34)	-2.1
15	15	1.126	0.23	0.47	(0.69, 1.31)	-4.2	0.69	(0.70, 1.30)	-2.3
16	16	0.864	0.226	0.46	(0.69, 1.31)	-4.2	0.67	(0.71, 1.29)	-2.6

17	17	-0.384	0.218	1.29	(0.69, 1.31)	1.7	1.2	(0.74, 1.26)	1.4
18	18	-3.278	0.266	5.11	(0.69, 1.31)	13.8	1.5	(0.52, 1.48)	1.9
19	19	-2.710*	1.015	3.5	(0.69, 1.31)	9.9	1.5	(0.61, 1.39)	2.2

Separation reliability = 0.984

Chi-square test of parameter equality = 960.90, df = 18, sig. level = 0.000

Table 3: Generalised item analysis - statistics.

Statistics	Value
N	80
Mean	46.58
Standard deviation	4.31
Coefficient alpha	0.86

Table 4: Range of performance tests for IMS and OMS.

Value	Implications for measurement	Item number
>2.0	Damaging the measurement system	11, 18, 19
1.3 - 2.0	Has no meaning for measurement	10
0.7 - 1.3	Useful for measurement	3, 4, 5, 8, 9, 17
<0.7	Not useful for measurement but not destructive	1, 2, 6, 7, 12, 13, 14, 15, 16

From the test item analysis data in Table 4, it was found that items 11, 18 and 19 had a value above 2, thus damaging the measurement system. Items 3, 4, 5, 8, 9 and 17 have a value range of 0.7 to 1.3, meaning they are useful for measurement. Items 1, 2, 6, 7, 12, 13, 14, 15 and 16 have a value below 0.7 which means that they are not useful for measurement but are not destructive. In view of the results, items 11, 18 and 19 were omitted. Item analyses for the omitted items are shown in Table 5, 6 and 7 respectively.

Table 5: Item analysis: item 11.

Item:11 (11) cases for this item 80 discrimination 0.21 weighted MNSQ 1.61 item delta(s): 4.55								
Label	Score	Count	% of total	Pt bis	t	(p)	PV1 avg:1	PV1 SD:1
2	2.00	62	77.50	-0.21	-1.87	(0.065)	-0.53	1.68
3	3.00	18	22.50	0.21	1.87	(0.065)	0.24	1.90

Table 6: Item analysis: item 18.

Item:18 (18) cases for this item 80 discrimination 0.04 weighted MNSQ 1.50 item delta(s): -9.84								
Label	Score	Count	% of total	Pt bis	t	(p)	PV1 avg:1	PV1 SD:1
2	2.00	9	11.25	-0.04	-0.34	(0.274)	-0.24	1.25
3	3.00	71	88.75	0.04	0.34	(0.274)	-0.37	1.81

Table 7: Item analysis: item 19.

Item:19 (19) cases for this item 80 discrimination 0.12 weighted MNSQ 1.50 item delta(s): -8.13								
Label	Score	Count	% of total	Pt bis	t	(p)	PV1 avg:1	PV1 SD:1
2	2.00	13	16.25	-0.12	-1.09	(0.279)	-0.70	1.53
3	3.00	67	83.75	0.12	1.09	(0.279)	-0.29	1.79

According to classical test theory (CTT) [20] for the test items as a measuring tool, the analysis results included in Table 5, 6 and 7 can be elaborated as follows. In regard to the level of difficulty, item 11was classified as very difficult because only 22.5% of the testees were successful in doing it, and it has the value of discrimination (bi-serial point) of 0.21. Item 18 was classified as very easy because 88.75% of the testees were successful in doing it, and it has the value of discrimination (bi-serial point) of 0.04. Item 19 was classified as very easy because 83.75% of the testees succeeded in doing it, and it has the value of discrimination (bi-serial point) of 0.12. Items 11, 18 and 19 have low discrimination points, so they did not qualify as items to measure creative thinking skills in PLC programming. So, both the level of difficulty and the discrimination points of these items were decisive in their exclusion in the measurement of creative thinking skills in PLC programming.

CONCLUSIONS

In regard to the results of this study, it can be concluded that:

1) the validation results of the instrument for creative thinking skills in PLC programming are very good, with the average Likert index value of 99.12%;

2) there are 16 instrument items that fit the model criteria and are in the IMS and OMS values ranging from less than 0.7 to less than 2;
3) the instrument reliability coefficient that was developed is in the *good* category, and equals 0.98;
4) the reliability coefficient based on testing is in the *good* category, and equals 0.86 (coefficient of alpha);
5) the highest level of students' creative thinking skills is demonstrated in the aspect of knowledge and use of resources, while the lowest is in the creative functioning aspect.

Overall, the instrument developed for testing students' creative thinking skills in PLC programming is suitable for that assessment.

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