The Effect of Integrating Error-Based Instruction with Ill-Structured Problem-Solving Game on Learning Disaster Education

Muhamad Aris Burhanudin[1], Chia-Yu Wang*[2] and Su-fen Chen[2]

[1]*Graduate of Graduate Institute of Digital Learning and Education of National Taiwan University of Science and Technology*
burhanudinaris@gmail.com

[2]*Professor of Graduate Institute of Digital Learning and Education of National Taiwan University of Science and Technology*
*chiayuwang@gapps.ntust.edu.tw

Abstract

This study aimed to investigate the effect of error-based problem-solving instruction on students' disaster management knowledge, problem solving skill and learning engagement. The participants were high school students in Indonesia utilizing an ill-structured problem-solving game, namely: *Stop Disaster*. Students of the experimental group (n=27) were placed in the error-based problem-solving (EPS) instruction condition and their cohorts of the control group (n=25) received the conventional problem-solving (CPS) instruction.

To examine students' disaster management knowledge, a set of multiple-choice question and its related reason were administrated as pre, immediate and delay test. For students' problem-solving skill, the sample t-test was used to compare the students' worksheet score before and after intervention. At last, multiple validations, such as professional and statistical validation, were used to validate the learning engagement questionnaires and a non-parametric test was used to examine the different learning engagement between experiment and control group.

The result indicated that the main time effect on the students' disaster management knowledge (immediate-delay test) was not significant but the knowledge improvement of students in experimental group was significantly higher than students in the control group. After evaluating the students' worksheet, the EPS did give higher effect on students' problem-solving skill than CPS. Moreover, both groups had same level of the learning engagement. Our finding on this learning model integration which was supported by quantitative evidence might suggest a more effective way to use the ill-structured problem-solving game in learning disaster educations.

Keywords— disaster education, learning engagement, error-based instruction, game-based learning, ill-structured problem-solving.

I. Introduction

These days, the occurrence and impact of natural disasters are increasing worldwide (Coronese et al., 2018). Natural disasters claimed various lives, damaged properties, and destroyed economies (Coronese et al., 2019). According to social scientists, educating people with the necessary disaster information are the best way to reduce the negative impact of natural disasters (Tsai et al., 2020). Some studies indicated that trained people in society can be prepared for disasters and respond better that untrained people with disaster education (Torani, 2019).

Several researchers used game simulation to engage students and promote disaster experience (Pereira et al., 2014; Tanes & Cho, 2013; Tsai et al., 2020). Among educational methods, using game is considered an engaging approach that focuses on emotional states, peer relations, communication, and active cooperation (Novak et al., 2019). By incorporating game simulation into disaster education, students will have more opportunities to apply their knowledge and skills to solve a variety of problems. They can test their different solutions and find the best one for a specific disaster problem. They have multiple opportunity to test their plan, for which such opportunities are hard to come by in the real world. Furthermore, disaster educational game (e.g., *Stop disaster!*) gives opportunities to shape players' ill-structured problem-solving skills.

Unlike the well-structured problem solving those students face in formal learning settings, ill–structured problem solving involves working on problems that are complex, ill-defined, and situated in the real world. Ill-structured problems are like those that we encounter in everyday life, in which one or several aspects of the situation are not well specified, the goals are unclear, and there is insufficient information to solve them (Sinnott, 1989; Xun & Ge, 2004). Those aspects caused the students often hold misconceptions, feel frustrated and only focus on the correct part. They often do not evaluate their errors and difficulties. On the CPS instruction, students are provided an incomplete problem and ask them to solve it. Adam et al (2014) argue that CPS can cause student engage in so much extraneous load that make them fail to abstract the solution to solve the problem. In contrast, integrating error-based problem-solving (EPS) instruction as guidance in this study offer enough challenge to foster generative load (Sweller et al, 2011). It should be able filling the gap of learning trough ill-structured problem-solving game better than conventional problem-solving (CPS) instruction. The findings potentially contribute to educators in constructing affordable instructional design by using ill-structured problem-solving game (*stop disaster!* game) for teaching and learning process in disaster education.

The current study aims to explore whether EPS has better effects on various learning outcomes, including students' disaster management knowledge, problem-solving skill and learning engagement than the CPS.

Based on the research purposes, the present study proposed the following research questions:

- Does EPS increase students' disaster management knowledge better than CPS?
- Does EPS foster students' problem-solving skill better than CPS?
- Does EPS enhance students' learning engagement better than CPS?

II. Method

Participants

The participants are 11th grade science program students in two bilingual science classes at a private high school in East Java, Indonesia. According to national curriculum of Indonesia year 2016, the students in 11th grade should learn about disaster education, namely Disaster Mitigation and Adaptation (Kamil et al., 2021). Two classes are each assigned into either the EPS (n=27, receiving error-based problem-solving) or the CPS (n=25, receiving conventional problem-solving) conditions. All participants have received the content on mitigation and adaptation to natural disaster before entering the problem-solving unit.

The design of the problem-solving instructions

The students in the EPS group were given incorrect/erroneous problem then the students are prompted to locate the error, explain the error and correct the error. The incorrect problem was from the print-out of other students result after applying their strategy on the previous game playing. In contrast, students in the CPS group received the print-out of the game start view (incomplete problems) and asked to solve those problems. Both groups used mini-paper to complete the instruction.

Instruments

To measure the gain of students' disaster management knowledge, a concept test consisting of 20 multiple-choice items and its related reasons were developed with some items adapted from Indonesia Ministry of Culture and Education. Items of the concept test covers 4 dimensions of disaster management activities, including mitigation, preparedness, response and recovery (Seaberg et al., 2017). Two experts in science and digital education helped established the content validity.

To assessing problem-solving skill, rubrics, adapted from Jonassen (2014) were developed to score students' responses to the learning worksheets. Each part of ill-structured problem-solving processes has 1-3 points and higher point shows better problem-solving skill.

To assessing learning engagement, 4 constructs of 5-points Likert scale survey from Wang's et al (2016) was adapted and modified so it is situated in the context of *Stop disaster!*. They are cognitive engagement (n=3, α = .78), behavioural engagement (n=2, α = .81), emotional engagement (n=4, α = .83), social engagement (n=2, α = .74).

Procedure

After the student got the prior knowledge about disaster management aligned with Indonesian curricula, a concept pretest was done. Then, the students were introduced about the game of *stop disaster!* and did the first game playing. after getting complete learning processes, all students were given a post-test for disaster management knowledge, post-questionnaires about learning engagement and did the second game playing. In each game playing the students had to fill the worksheets and the worksheets were examined to measure students' problem-solving skill before (as PS pre-test) and after (as PS post-test) the intervention. Finally, after 4 weeks, students were given the delayed post-test on disaster management knowledge to measure students' deeper learning experience that persists over time (Adams et al., 2014; Dunlosky et al., 2013).

III. Result

To answer RQ.1, the repeated measures ANCOVA as a parametric statistical method for normally distributed data was used to examine students' disaster management knowledge in post and delayed tests with pre-test (M_{EPS}=63.48, SD_{EPS}=9.17, M_{CPS}=71.33, SD_{CPS}=7.97) as the covariate and compare it among two groups. The result indicated that the post hoc test result showed that the students' post test score of disaster management knowledge in the EPS group increased significantly higher than students in the CPS group (M_{diff}=8.30, SE=2.08, p<.05). **Figure 1** reported the improvement of students' disaster management knowledge with pre-test as a covariate. However, in case of time interaction between immediate and delayed post, EPS and CPS instruction did not reach statistically difference on the students' disaster management knowledge scores [F (1, 49) = 15.96, ρ > .05, η2 = 0.25]. **Table 1** showed the result of repeated measures ANCOVA of students' disaster management knowledge.

Table 1
The result of repeated measures ANCOVA of students' Disaster Management Knowledge

Group	Test	N	M(SD)	Adjusted M	SE	*F* (1,49)	*p*	*η2*
EPS	Post	27	83.74 (8.11)	84.958[a]	1.39	15.96	0.00	0.25
	Delay	27	82.41 (9.59)	83.971[a]	1.77			
CPS	Post	25	77.44 (6.43)	76.133[a]	1.45			
	Delay	25	77.89 (9.16)	76.201[a]	1.85			

[a] Covariates appearing in the model are evaluated at the following values: Pre-test = 67.2538

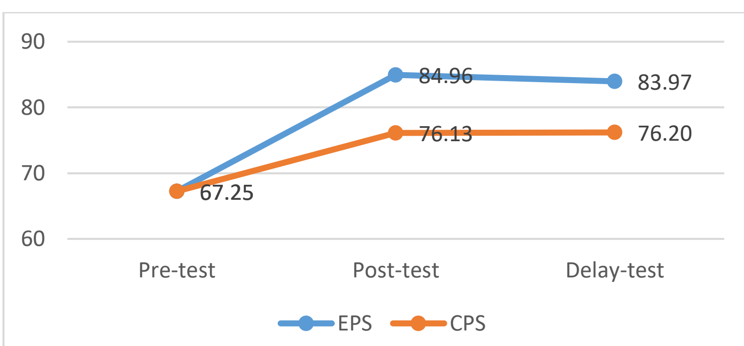

Figure 1. Improvement of disaster management knowledge

For the answer of RQ.2, we created problem-solving performance rubrics that describe the levels of acceptable answer on the students' worksheet. Then, due to the scoring data of students' worksheet were distributed normally, ANCOVA test as parametric statistical method was used to compare the students' problem-solving skill post-test with pre-test as a covariate. The result showed that EPS instruction foster students' problem-solving skill statistically better than CPS instruction ($p < 0.05$). **Table 2** showed the result of ANCOVA test of the student worksheet scoring.

Table 2.
The result of ANCOVA test of problem-solving skill

PS Skill	Groups							
	EPS (N=27)		CPS (N=25)		EPS vs CPS			
	M (SD)	SE	M (SD)	SE	M_{diff}	F (1, 49)	SE	*p*
Pre-Test	49.07 (11.86)		41.67 (9.92)		13.90*	15.85	3.49	.000
Post-Test	75.93 (14.12)		69.67 (13.15)					
Post-Test[a]	74.30	2.35	60.41	2.45				

[a] Covariates appearing in the model are evaluated at the following values: Pre-Test = 45.5129

To answer RQ.3, the Mann-Whitney U test as a non-parametric statistical method was done to determine the difference on students' learning engagement data that were not distributed normally. The result showed that EPS had same level of students' learning engagement with CPS. However, if we analysed further on each factor of learning engagement, we found that EPS had given significantly higher social engagement than CPS had ($M_{different}$=10.94, p<.05). The result of the Mann-Whitney U test of students' learning engagement is presented in **Table 3.**

Table 3.
Mann-Whitney U Test Result of Students' learning engagement

	EPS Group (n = 27)		CPS Group (n = 25)				
	Mean Rank	Sum of Ranks	Mean Rank	Sum of Ranks	*U*	Z	*P*
CE	49.43	1334.48	49.62	1240.46	1135.50	-0.034	>.05
BE	49.83	1345.28	48.99	1224.67	1120.50	-0.146	>.05
EE	48.56	1311.08	50.99	1274.67	1083.50	-0.423	>.05
SE	53.74	1451.03	42.80	1070.07	885.50	-1.901	<.05
TLE	50.68	1368.36	47.64	1191.00	1069.50	-0.515	>.05

TLE: Total Learning Engagement, CE: Cognitive Engagement, BE: Behaviour Engagement, EE: Emotional Engagement, SE: Social Engagement

IV. Discussion

Empirical contributions

As a result, the findings revealed that the students' disaster management knowledge improved significantly from the pretest to the posttest in both groups, but students in the EPS group were significantly higher than those in the CPS group both in the immediate posttest (p<.01) and delayed posttest (p<.01). This pattern of result is a new major contribution to the research literature on integrating erroneous examples with ill-structure problem solving game. It was also consistent with some previous studies (McLaren & Isotani, 2011; Sweller et al., 2011) that had documented the superiority of instruction using worked examples, especially erroneous examples because it encourage students to engage in generative processing, as they explain to themselves why a particular part of the problem is incorrect (Durkin & Rittle-Johnson, 2012). Therefore, EPS instruction, by providing erroneous examples, may increase students' disaster management knowledge better that CPS instruction.

In this study, we also found another important finding that represent a new empirical contribution to the research literature. Even, the problem-solving skill score in both groups showed a significant improvement, the students' problem-solving skills in EPS group was statistically higher than those in CPS group. This finding aligned with the perspectives of constructivism, learners can construct new knowledge through trial and error, picking up messages from past experience, or exerting metacognitive power (Chien & Chen, 2017). We also argue that students in EPS group may be able to construct the correlation between the EPS steps (Adams et al., 2014) and the ill-structures problem-solving processes steps (Xu & Ge, 2004) that were being the basis of creating problem solving performing rubrics in this study. For examples, the first step of EPS is "explaining the error". It is a little bit similar with the first step of ill-structure problem solving processes, "Problem representation". Therefore, the students can construct new knowledge by picking up messages from past knowledge. This finding also aligned with Polya (1957) statement in which, to be an effective problem-solver, the student must find the connection between the known-data and the unknown-data. Some question prompt that Polya suggested to help fostering devising a plan in problem solving skill step, "Have you seen it before?" or "have you seen the same problem in a slightly different form?". It means EPS instruction steps may foster students' problem-solving skill better than CPS instruction steps.

Finally, the finding showed that there was no statistically difference of students' learning engagement among both groups. It means both EPS and CPS were able to foster learning engagement in a same level when they were integrated with ill-structured problem-solving game. However, the deeper analysis on each construct of learning engagement revealed that EPS fostered social engagement statistically better than CPS did ($M_{different}$=10.94, p<.05). Wang et al (2016) defined social engagement includes the quality of social interactions with peers and adults while learning. It means that EPS may provide more opportunities for students to create higher quality of social connection with one another by exchanging ideas and sharing experience to solve the provided error. This finding also aligned with previous study (Wang & Eccles, 2013), students who want to form positive relationships with their peers are also more likely to have high academic achievement.

Limitation and future directions

One limitation of this study is that we did not compare the erroneous/incorrect example with correct example. The reasons of excluding correct example condition are: the first, in the present study we aimed to compare the most common control condition in the game environment (solving the problem) to the less learning condition (working with erroneous examples) (Adam et al, 2014). Second, analysis of game environment showed that, as a control environment, problem-solving condition was more suitable to reflect the game problem than correct example condition. Nevertheless, to more completely compare instructional approaches, in a future study it would be useful to include a worked examples condition.

Another limitation, we only examined the learning engagement after the learning processes had been done. We assumed that all students were novice and had same level of engagement in learning disaster through educational game. However, to provide more accurate result, it would be useful to collect pre-learning engagement.

In addition, efforts can be put into addressing various other educational game, such as physics game or mathematic game, to test if similar results can be achieved through employment of the error-based pedagogy.

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