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Examining the Effect of Socially Engaged Art Education with Virtual Reality on Creative Problem Solving

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ABSTRACT: The goal of this study was to examine the effect of engaging students in socially engaged art (SEA) education to create 3D virtual worlds for fostering creative problem-solving (CPS) skills. The study was conducted with 135 students (aged 16) of boys' high school in Korea who participated in the SEA program through four stages: Stage 1- appreciation and interpretation of artwork about social issues; Stage 2 - discussion on the potential solution to the selected social issue; Stage 3 - creating a 3D virtual world k to express proposed solutions; and Stage 4 - experiencing and sharing 3D virtual worlds. The following research questions guided the study: (1) What is the effect of SEA education with VR on students' CPS? (2) How are the students' CPS as expressed in their artifact (essay and VR work)? (3) What are the relationships between students' CPS and their artifact (essay and VR work)? For data collection, we administered the instrument to measure students' CPS skills in three areas (higher-order thinking, divergent thinking, and problem-solving) and also evaluated student essays and VR work to examine CPS specific to art education. Overall, the results indicate that the students improved their CPS skills significantly after participating in the SEA program. The CPS skills had significant relationships with the essay scores, whereas only one significant relationship was found between CPS and VR work. This study provides empirical findings concerning how the formal school curriculum can introduce students to an authentic context concerning social issues through artmaking practices with VR.

Keywords: Virtual reality (VR), Socially engaged art (SEA), Creative problem solving (CPS)

1. Introduction

Authentic learning environments present learners with complex real-life contexts and problems (Herrington & Oliver, 2000). Generally described as ill-structured or wicked problems, such authentic problems tend to be challenging to solve but stimulate students' creativity to go beyond well-known solutions. In K-12 education, pedagogical approaches that engage students in such authentic problem-solving activities (e.g., design thinking, problem-based learning, project-based learning, and service learning) have been emphasized in the school curricula to foster creative and critical thinking skills (Dorst, 2006; Hmelo-Silver, 2004).

In this study, we focus on a pedagogical approach called "socially engaged art" (SEA) in education as a particular mechanism for introducing authentic problems for learning through art practices and engaging students in a creative problem-solving process. SEA is viewed as a transpedagogy that blends "educational process and art making" (Helguera, 2011, p. 77). SEA has attracted considerable attention as a new direction for contemporary art education that expands the goal of art education beyond the traditional emphasis on teaching art skills and techniques disconnected from learners' lives. In SEA education, learners are engaged in meaning-making practices concerning various socio-cultural issues through participatory activities such as appreciation, critiques, and artwork creation.

With this backdrop, this study examines the effect of engaging students in SEA education to create 3D virtual worlds for fostering creative problem-solving (CPS) skills. In this study, we view VR as a relevant platform for students to express their creative ideas with the unique affordances of VR such as high representation fidelity and embodied actions (Dalgarno & Lee, 2010; Fowler, 2015). The existing literature on VR in the K-12 context has mainly focused on investigating how students consume VR content for cognitive learning (Maas & Hughes, 2020). The novelty of this study lies in that it examines the effect of VR as a tool for creation beyond consumption, positing students as a designer of VR content for expressing solutions to authentic social problems.

The following research questions guided this study: (1) What is the effect of SEA education with VR on students' CPS? (2) How are the students' CPS as expressed in their artifact (essay and VR work)? (3) What are the relationships between students' CPS and their artifact (essay and VR work)? By examining these questions, this study aims to provide empirical findings concerning the effect of implementing the SEA approach with VR in the K-12 school context, which has been rarely reported in the existing literature.

2. Theoretical backgrounds

2.1. Creativity and creative problem solving

Creativity has been actively studied since the late 1950s. While there is no unified consensus on the concept of creativity, creativity has been approached as cognitive ability or affective disposition. Guilford (1967) sought to understand creativity through divergent thinking. He regarded creativity as the power to produce new and novel things, and not as a special talent of only certain people, but as an ability that everyone possesses. Torrance (1967) views creativity as the process of sensing gaps and formulating, testing, and retesting ideas to seek solutions. Sternberg and Lubart (1999) describe creativity as the confluence of multiple components such as intrinsic motivation, domain knowledge, and creativity-relevant skills (e.g., cognitive style, work style, and heuristics).

Scholars adopting cognitive approaches argue that creativity is manifested in problem-solving situations. Mayer (1989) defines creativity as the ability to solve problems that one has not previously learned to solve. Osborn (1953) built the foundation of CPS and proposed the seven-step CPS process: orientation, preparation, analysis, hypothesis, incubation, synthesis, and verification. Many variations of the CPS model do not deviate much from these steps. In CPS, learners are faced with complex problems and create solutions by identifying key factors and seeking new alternatives in a problem space. The difference between CPS and general problem solving (GPS) lies in whether iterative processes occur intentionally. Specifically, GPS is achieved by analyzing a problem space and then using existing knowledge to satisfy the solution requirements. While CPS goes through a similar process, it repeats the process of returning to the problem space to derive better solutions by reducing obstacles and constraints.

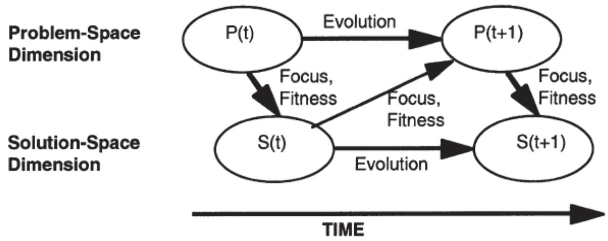
The iterative nature of CPS was further emphasized by Treffinger (1995) who developed the framework of CPS by moving away from fixed and sequential approaches. Treffinger suggested two important promises of CPS research. First, anyone might become creatively productive in meaningful ways and learn about their creative abilities. Second, CPS is not a simple, step-by-step process. With that, the CPS framework proposed by Treffinger includes three major components: understanding the challenge, generating ideas, and planning for action (Isaksen et al., 2000). Similarly, Mayer (1989) contends that teaching strategies to help students to be creative include (a) developing many component skills rather than a single monolithic general ability, (b) focusing on the process rather than the product of problem-solving, and (c) creative learning skills within specific content domains rather than as a separate course in general learning skills.

2.2. Creative problem solving in art education

By nature, art is a problem-solving process to create new artifacts, and creativity is the key driving force in artmaking. The co-evolution framework by Maher et al. (1996) helps understand how CPS processes unfold in art education. Traditionally, creativity has been regarded as a mysterious area in art and design education. Even those who are regarded as creative cannot identify significant events or factors that spurred their creative ideas due to the retrospective nature of such events (Wiltschnig et al., 2013). The co-evolution framework in Figure 1 suggests that creative design can be understood from two integrated dimensions: the problem-space and the solution-space. Maher et al. (1996) stated that the two spaces interact over time like evolution in the problem-design exploration process. The diagonal movement indicates that the problem leads to a solution (downward arrow), or the solution refocuses the problem (upward arrow). A fitness function indicates how close a given design solution is to achieving the current state. The definition of the problem can change according to the current state of the solution space, implying a co-evolution process.

Based on the co-evolution framework, Dorst and Cross (2001) studied nine industrial designers on their creativity through the think-aloud protocol. They found that designers used various approaches, such as analysis, synthesis, and evaluation to discover solutions, continuously crossing between the problem and solution spaces. Similarly, Maher and Tang (2003) studied the interaction between the problem and solution spaces through a protocol analysis of designers. They found that human designers had limited cognitive memory but strong reasoning between the problem requirements and the solution space. While these findings are interesting, the application of the co-evolution framework has been limited to the study of professional designers. Research in the K-12 context, such as examining novice designers, is still lacking.

Figure 1. Co-evolution of the problem and solution spaces (Maher et al., 1996)



2.3. Socially engaged art education

As a pedagogical stance, SEA is built upon constructivist approaches to provide a new lens to examine the goal and power of art in education. Learners in SEA education are engaged in art practices "that are authentic to the ways artists in that field actually work and feel empowered enough in the situation to be willing and able to bring their own ideas to the process" (Wiggins, 2015, p.116). Helguera (2011) argued that traditional pedagogy in art education has failed to recognize three elements: (1) recognizing the creative performativity of the act of education, (2) the collective construction of an art milieu, and (3) knowing the artwork is not the end but is a tool for understanding the world. In essence, SEA in education emphasizes problem-solving through collaborative learning and the criticality of educational practices that are "collaborative and encourage cross-disciplinary dialogue and citizen engagement" (Rochielle & Carpenter, 2015, p. 131). Further, Schlemmer et al. (2017) succinctly pointed out the pedagogical role of SEA as stretching "beyond the production of aesthetically pleasing art objects to foster a dialog that integrates artistic practices, pedagogical processes, and creative possibilities in pursuit of a more equitable world" (p. 56). Hence, when SEA is integrated into the art education curricula, learning processes are often structured with collaborative, cross-disciplinary, and creative activities that engage students to create artwork under the themes of social change and civic engagement.

Despite the increased interest in SEA, research studies that examine the effect of SEA on student learning are still scarce. The existing literature is mostly qualitative and narrative. While a few studies are available, the existing studies on SEA education present an important message that learning in art education is not merely consuming content and developing art techniques but is creating value through artmaking practices. For instance, Roberts et al. (2008) reported the Storytelling Project curriculum where high school students were engaged in the critical examination of racism and social justice through storytelling and art. The students explored critical questions about racism expressed in the various forms of stories, such as historical documents and media with the theme of the "American dream," and then created counter-stories offering their imagination of new possibilities. The analysis of the student discourse revealed that art played a critical role in developing student agency and imagining alternatives. Chung and Li (2020) presented the possibility of integrating SEA for young learners. They attempted to teach elementary students about social justice issues in American society through artwork on the theme of homeless. The students were first exposed to the mural artwork by Skid Robert, who expressed the living conditions of homeless people, brainstormed ideas for alleviating the issues, and then finally drew a home for homeless people through printmaking. The study found that the students could discuss homeless issues meaningfully and critically as well as learning about art production skills.

2.4. Virtual reality for interpretation and expression

The preceding sections discussed the role of SEA in introducing authentic contexts and problems to learners and the mechanism of CPS from the co-evolution view. What is less elaborated in the literature on SEA and CPS is the space for learners to express their ideas and imagination, which we call an "interpretative and expressive space." In the design field, various technological tools and platforms support the process of CPS, especially dynamic interactions between the problem and solution spaces. For instance, Choi and Kim (2014) examined how the cognitive use of digital tools influenced the ability to derive creative design concepts among Korean university students majoring in design. Using digital tools for deriving ideas, the students expanded their creative thinking from a new viewpoint and transformed ideas using metaphors, analogies, and reasoning. Tark and Yoo (2018) found that VR as an expressive platform positively affected students' creative problem-solving ability and learning interest in social studies.

The present research is particularly interested in the affordances of VR as an interpretative and expressive space where students can express their creative ideas with 3D multimodal objects and images. The primary features of VR for learning are *immersion*, *real-time interaction*, and *reality*. The comprehensive literature review on the effect of immersive VR indicates that educational interventions with immersive VR produced significant advantages compared to non-immersive methods (Hamilton et al., 2021). Recent studies emphasize the importance of using VR to promote creative, comprehensive, and critical thinking in learners, beyond simple interest and novel experiences (Chang et al., 2020).

However, one promising area that has been less explored in the existing literature is to engage learners as the designer of VR content. While immersive experiences are beneficial for learners to explore virtual spaces, most VR-infused approaches tend to make learners passive users who experience the predesigned content. In the review of the literature on VR, AR, and MR in K-12 education, Maas and Hughes (2020) argue that most research used these advanced technologies for consuming materials and more research is needed to explore how students use these technologies as "a means of creation and discovery" (p. 245). Indeed, empowering students as a creator of VR content has pedagogical value in that students are engaged in complex problem solving through their creativity (Lim, 2008). Hu-Au and Lee (2017) contended that VR as a pedagogical tool presents several opportunities, such as providing authentic experiences, allowing new perspectives and empathy, and supporting creativity through visualization. When engaging learners to design VR content, it is important to present problems relevant to the students' interests and experiences to encourage them to actively participate with high motivation and play the role of creators (Choi et al., 2016). A recent study with junior high school students in Taiwan shows that design lessons with VR support the more engaging, exploratory, and reflective process of creative design than the lessons without the use of VR (Chang et al., 2020)

3. Methods

3.1. Research participants and context

This study was implemented at a boys' high school in a metropolitan city in Korea for about three months in 2019. The participants were 135 male students in the tenth grade (aged 16) who participated in six lessons in the SEA program for two months during the formal classroom hours of the art class. The designed SEA program included various activities to engage students to create artwork that visualizes their creative solutions to authentic social issues using VR as an interpretative and expressive space (see Section 3.2). The present research did not have a control group since the school policy was for the teacher to conduct all classes with the same lesson and activities. Prior to this study, the participants did not have any previous experiences with SEA programs and any VR authoring tools.

3.2. Lesson design and implementation

In this study, one high school teacher and two art education experts collaborated to design the SEA education program. The teacher had 10 years of teaching art in a high school. The two experts include one professor in art education with 20 years of teaching experience and another professor who teaches virtual reality in art education. In the SEA program design, a particular emphasis was placed on presenting authentic situations in which learners could realize the complexity of various social problems in society. An authentic context in this study refers to social problems in real-life situations and collaborative learning activities. Based on Maher's framework on the co-evolution of the design exploration, we designed learning activities to enable students to continuously navigate between the problem space and solution space to search for solutions. In the problem-space, the students were supposed to appreciate and unpack the messages that various artworks reflect, such as racism, environmental protection, and global warming. In the solution space, students used VR to create work that expressed the possible solutions to social problems.

Class activities were conducted face-to-face in a computer lab. Figure 2 presents the CPS activities in four stages. Stage 1 is the appreciation and interpretation of artwork about social issues. Stage 2 involves the discussion of the potential solution to the selected social issue. Stage 3 includes creating a 3D virtual world that expresses the proposed solution. In Stage 4, students experience and share the created 3D virtual worlds. Table 1 shows how the design of the SEA learning activities in each stage is guided by the design framework of authentic learning environments by Herrington and Oliver (2000).

In Stage 1, the students understood the relationship between art and society through various pieces of artwork. Table 2 presents the exemplary artwork used in the lesson to facilitate student discussion about authentic problems under three themes: political issues, natural environments, and social problems. Each artwork was presented digitally to the student through the projector in a computer lab. We used Feldman's (1992) art criticism model to guide critical thinking during the appreciation of various artwork. Feldman's model includes four steps in art criticism: description, analysis, interpretation, and judgment. Students did not need to perform the four-stage structure in a linear, sequential manner. Teachers engaged students to interpret artwork through their subjective experiences and to exchange ideas in class discussions.

Figure 2. Four stages of the socially engaged art (SEA) education program in this study

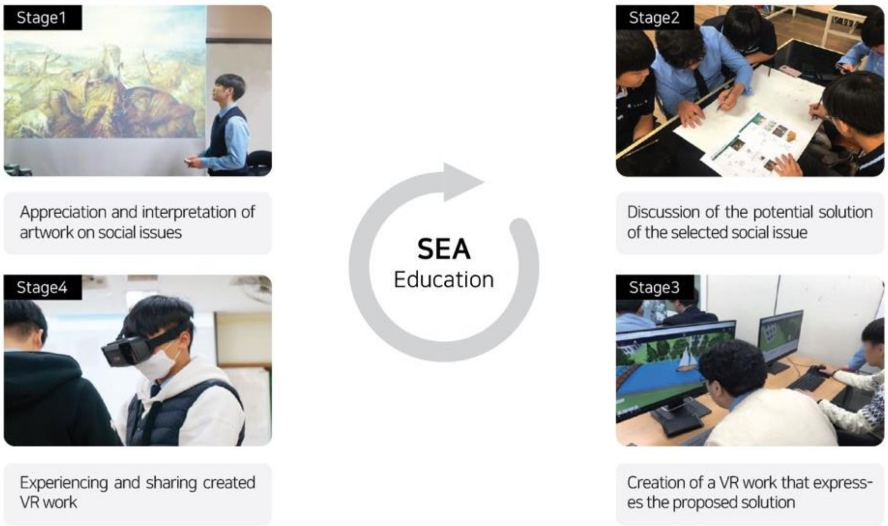


Table 1. Design guidelines of authentic learning environments implemented in this study

SEA education	Design guidelines (Herrington & Oliver, 2000)	Implemented in this study
Stage 1	• Provide authentic context and activities	• Students appreciate and interpret artwork on social issues to understand the relationship between art and society. • Students learn about Feldman's (1992) art criticism model as authentic activities by artists.
Stage 2	• Support collaborative construction of knowledge	• Students work in groups to brainstorm and discussion potential solutions to the selected social issue.
Stage 3	• Promote articulation and reflection • Provide coaching and scaffolding	• Students create a 3D virtual world to articulate and visualize their proposed solution. • Students write an essay about their VR work to reflect on their learning process. • The teacher provides necessary scaffolding to guide students to create a 3D virtual world in a computer-based environment
Stage 4	• Provide multiple roles and perspectives • Provide authentic assessment of learning within the tasks	• Students experience 3D virtual worlds created by other groups, switching their roles from a creator to a user. • Students are evaluated on the artifact created during the learning process rather than separate formal tests.

In Stage 2, the students formed groups of five to six members to select a particular social issue of their interest and discussed ideas for potential solutions face-to-face in a computer lab. Adopting the critical inquiry process by Geahigan (1999), the students were asked to search for external resources to organize and support their solutions. Brainstorming ideas on a large paper also facilitated the concretization of ideas and group discussions. The teacher carefully observed the process of group discussion and scaffolded students to solve problems by asking questions and providing necessary resources. For the iterative nature of CPS, the teacher helped the groups continuously navigate between the problem space and potential solutions and to reduce constraints in the problem space for deriving better solutions.

Stage 3 involves the creation of VR work to express the proposed solution. First, the students learned about the key functions of CoSpaces Edu, a web-based VR authoring software for easily creating 3D virtual worlds. With a block-based programming language called CoBlocks, students new to coding or unfamiliar with programming could easily create a 3D virtual world. Students in groups built a virtual space by choosing 3D objects, such as cities, people, animals, and plants, and various materials and colors, adding animation effects through coding.

In Stage 4, the groups formally presented their 3D virtual world in the online space available in CoSpaces. This stage also allowed students to experience the 3D virtual worlds created by other groups using head-mounted displays (HMD). For the safety of students, they formed a pair, and one student was responsible for checking whether there was any danger in the physical space while the other student was experiencing the 3D virtual worlds with HMDs (model: LEAPmotion VR2).

Table 2. Themes of social problems expressed in the artwork

Themes	Theme 1: Artwork that reflects political issues (e.g., war, refugees, homelessness, racism & feminism)	Theme 2: Artwork that considers the natural environment (e.g., global warming & ecosystem)	Theme 3: Design that intends to solve social problems (e.g., universal design, nudge design, CPTED, green design & sustainable design)
Problem expressed in exemplary artwork	 Racism	 Global warming and deforestation	 Environmentally friendly products

Note. CPTED: crime prevention through environmental design.

3.3. Data collection and analysis

3.3.1. Creative problem solving

We measured students' CPS skills through an instrument developed by Chi and Ju (2012). The instrument was developed to measure CPS skills as a general competency in all subject areas of the school curricula, reflecting the policy initiative by the Korean Ministry of Education to foster creatives leaders in a future society. We chose this instrument because it includes the core aspects of CPS emphasized in this program and was validated with 530 middle and high school students in Korea. The CPS instrument focuses on the cognitive dimension of creativity based on the theoretical perspectives of Guilford (1967) and Torrance (1967). Guilford (1967) associated divergent thinking with creativity and emphasized one's ability to generate multiple alternative solutions to a given problem. Torrance (1967) further elaborated that creativity is the process of sensing gaps and formulating, testing, and retesting ideas to seek solutions. Based on these theoretical perspectives, this instrument includes 13 items to measure the cognitive aspect of CPS on a 5-point Likert scale (1= Strongly disagree, 5=Strongly agree) in three areas: (a) higher-order thinking (4 items), (b) divergent thinking (5 items), and (c) problem-solving skill (4 items). Higher-order thinking is defined as an ability to logically analyze and synthesize what is learned. Divergent thinking measures an ability to deviate from a fixed frame for a problem and to derive several possible alternatives to generate novel and unique ideas. Problem-solving skill focuses on an ability to solve a given problem with diverse approaches and perspectives.

To ensure the validity of the instrument, we conducted reliability and factor analyses. The value of Cronbach's α was .897, which indicates a good internal consistency. The instrument was administered before and after the implementation of the designed SEA program. As mentioned earlier, since there was no control group in this study due to the school policy, we used a within-group comparison (pre-test and post-test) rather than a between-group comparison. A paired samples t-test was conducted to measure the effect of the SEA program on students' CPS.

3.3.2. Artifact evaluation: Essay and VR work

Since the above self-reported instrument could be subjective and measures CPS as a general competency, we collected additional qualitative data (i.e., essay and VR work) to examine students' CPS specific to the context of art education from multiple data sources. Developing a critical stance toward various social problems is one of the crucial goals advocated in SEA education. Hence, we collected and analyzed individual students' essays to measure the extent that students who participated in the designed SEA program developed their critical inquiry into art. The students were asked to write an essay about their VR work following the art criticism model by Feldman (1992): description, formal analysis, interpretation, and judgment. An essay template that guides the four elements of art criticism was provided to guide students' thinking processes.

We used the Art Criticism Assessment Rubric (ACAR) to evaluate student essays. Tam (2018) developed ACAR to evaluate art criticism by the Hong Kong Examinations and Assessment Authority. ACAR consists of eight elements for evaluating art criticism: (1) description, (2) formal analysis, (3) interpretation, (4) judgment, (5) application of aesthetic and contextual knowledge, (6) use of researched materials, (7) originality and balanced views, and (8) presentation, organization, and structure. The first four elements are based on Feldman's art criticism model, which is explained above. Next, the criteria "application of aesthetic and contextual knowledge" and "use of researched materials" in ACAR reflect Geahigan's inquiry-based art criticism model. Geahigan (1999) argues that art criticism is a critical inquiry process where students are engaged in searching for contextual knowledge and constructing their understanding of the artwork, beyond simple observation. Last two criteria, "originality and balanced views" and "presentation' measure students" intellectual writing skills. Since art appreciation and criticism theories by Feldman and Geahigan are included in the high school art curriculum in Korea and the students in this study were guided by these theories in the lessons, we decided that ACAR was suitable for this study as an evaluation rubric.

Some modifications to the original ACAR were made to make the rubric relevant to the context and purpose of the present study. The modified rubric has nine elements, as listed in Table 3. First, we used Elements 1 to 4 of ACAR that represent the four-stage structure of the art criticism model by Feldman (1992) to evaluate students' art criticism essays. This part mainly evaluates individual students' critical thinking processes and understanding of the problem-space dimension. Second, Elements 5 and 9 were used to evaluate students' VR work as the product of the solution-space dimension. Elements 5 to 7 were taken from Tam (2018) to mainly measure critical inquiry expressed in VR works. In addition, we created Element 8 (creative expression) and Element 9 (VR functions) to measure how the designed VR work represents students' creativity and the affordances of VR. The rubric uses a 10-point scale for each element: Very poor (2), Poor (4), Average (6), Good (8), and Excellent (10). Following the guideline by Tam (2018), the marks for (3) Interpretation and (5) Application of Aesthetic and Contextual Knowledge were doubled (total of 20 marks) as the core of higher-order thinking in art criticism.

Table 3. Elements and theoretical grounds of the evaluation rubric

Co-evolution in the design process	Elements	Evaluation target
Problem-space dimension	(1) Description (2) Formal analysis (3) Interpretation (4) Judgment	Art criticism essay (individual)
Solution-space dimension	(5) Application of aesthetic and contextual knowledge (6) Use of researched materials (7) Originality and balanced views (8) Creative expressions (9) Virtual reality functions	VR work (group)

Two raters (the teacher and one of the researchers) evaluated the student essays and VR work based on this rubric. Due to the large volume of data for evaluation, the teacher acted as the main rater to evaluate all data, whereas the researcher analyzed 30% of the data randomly selected from the pool. The inter-rater reliability was .980 for the student essays and .942 for the VR work, which indicates a high consistency between the two raters. Table 4 presents selected 3D virtual worlds based on the rubric scores in three levels (high, medium, and low) and QR codes to access each VR work.

Table 4. Examples of 3D virtual worlds by evaluation levels

	High	Medium	Low
Virtual reality work			
Problem	Water shortage in developing countries	Gender discrimination	Global warming
QR code to access VR work	Water short	Gender disc	Global warm

4. Results

4.1. Changes in creative problem-solving skills

First, factor analysis was conducted to verify whether the instrument accurately measures the three aspects of CPS. The suitability of the data for the factor analysis was determined by using the Kaiser Meyer Olkin (KMO) and Bartlett's test. The KMO values between .8 to 1.0 indicate that the sampling is adequate. As presented in Table 5, the KMO measure of sampling adequacy was .883, which is an acceptable value. The result of Bartlett's test of sphericity was statistically significant ($p < .05$). With that, we concluded that the data was suitable for the factor analysis. Next, exploratory factor analysis was performed with the principal axis method as the extraction criterion with varimax rotation. To determine the number of factors, we used the scree plot and Kaiser's criterion that the eigenvalue must be equal to or greater than 1.0. The cut-off value of factor loading was set at 0.4 or higher. After removing one item in higher-order thinking due to the low factor loading, we confirmed the three-factor structure of CPS (i.e., higher-order thinking, divergent thinking, and problem-solving skills).

Table 5. Kaiser–Meyer–Olkin (KMO) and Bartlett tests

Kaiser–Meyer–Olkin measure of sampling adequacy		.883
Bartlett's sphericity test	Approximate Chi-square	2351.321
	df	378
	Sig.	.000

Table 6. Descriptive statistics of pre-test and post-test for three variables of CPS

	Item	Pretest		Posttest	
		Mean	*SD*	Mean	*SD*
Higher-order thinking	(1) I fully understand what I have learned and apply it to other areas.	3.01	.96	3.53	.89
	(2) I logically analyze complex phenomena and grasp them as a whole.	2.76	.88	3.38	.91
	(3) I synthesize various pieces of information in context.	3.01	.88	3.58	.81
	Total	2.92	.75	3.50	.78
Divergent thinking	(4) I try new ideas or approaches to solve problems.	3.10	.92	3.61	.84
	(5) I do my assignments in a unique and individual way.	3.07	.87	3.63	.87
	(6) I tend to come up with a lot of ideas in a short time.	2.81	.97	3.51	.94
	(7) I tend to come up with a lot of new and original ideas.	2.95	.94	3.65	.84
	(8) I refine my thoughts and develop them into good ideas	3.08	.93	3.62	.88
	Total	3.00	.75	3.61	.68
Problem-	(9) I think and implement a solution to a problem	3.05	.84	3.67	.72

solving skills	from many angles.				
	(10) When faced with a difficult task to solve, I think of a number of alternatives.	3.30	.84	3.70	.82
	(11) I gather information related to a problem and draw a reasonable conclusion.	3.06	.86	3.74	.79
	(12) I expect the consequences of a solution to the problem in many ways.	3.08	.95	3.76	.79
	Total	3.12	.71	3.72	.64

Table 6 presents the descriptive statistics of students' CPS before and after participating in the SEA program. In the pre-test, the mean scores were 2.92 (*SD* = .75) for higher-order thinking, 3.00 (*SD* = .75) for divergent thinking, and 3.12 (*SD* = .71) for problem-solving skills. After participating in the SEA program, the students demonstrated increases in all three variables. In the post-test, the mean scores were 3.50 (*SD* = .78) for higher-order thinking, 3.61(*SD* = .68) for divergent thinking, and 3.72 (*SD* = .64) for problem-solving skills. Overall, the mean scores in each variable of CPS improved about 0.6 from the pre-test score.

Next, we conducted a paired samples *t*-test to examine the significance of the changes between the pretest and posttest scores. As listed in Table 7, the differences were statistically significant for all three variables: higher-order thinking (t = 6.992, p < .05), divergent thinking (t = 9.324, p < .05), and problem-solving skills (t = 7.908, p < .05).

Table 7. Paired samples *t*-test results for each of the three variables in CPS

Posttest-pretest	Mean	*SD*	*SE*	*t*	*df*	*p*-value
Higher-order thinking	.57	.94	.08	6.992^{*}	134	.00
Divergent thinking	.60	.75	.06	9.324^{*}	134	.00
Problem solving skills	.60	.88	.07	7.908^{*}	134	.00

Note. $^{*}p$ < .05.

4.2. Artifact evaluation

Table 8 presents the scores of the artifact evaluation. First, in the essay evaluation based on the rubric, the mean values were 6.66 (*SD* = 2.13) in description, 6.74 (*SD* = 2.23) in formal analysis, 13.67 (*SD* = 4.65) in interpretation, and 6.16 (*SD* = 2.43) in judgment. Overall, the results revealed that student scores in the four art criticism areas were slightly above the mid-point of the scale. The mean for the total score was 33.23 (*SD* = 10.39) out of 50. Second, the evaluation of the VR work indicates that the score for creative expression was the highest among all the elements whereas the score for the use of researched materials was the lowest. Specifically, the mean values were 13.84 (*SD* = 3.79) for the application of aesthetic and contextual knowledge, 6.22 (*SD* = 1.96) for the use of researched materials, 6.77 (*SD* = 1.85) for originality and balanced views, 7.02 (*SD* = 2.48) for creative expressions, and 6.53 (*SD* = 2.05) for VR functions. The mean for the total score was 40.39 (*SD* = 10.92) out of 60.

Table 8. Descriptive statistics for the rubric evaluation of essay and VR work (n = 135)

	Element (total mark)	Min	Max	Mean	*SD*
Art criticism essay	Description (10)	2.0	10.0	6.66	2.13
	Formal analysis (10)	2.0	10.0	6.74	2.23
	Interpretation (20)	4.0	20.0	13.67	4.65
	Judgment (10)	2.0	10.0	6.16	2.43
	Total (50)	10.0	50.0	33.23	10.39
VR work	Application of aesthetic and contextual knowledge (20)	4.0	20.0	13.84	3.79
	Use of researched materials (10)	2.0	10.0	6.22	1.96
	Originality and balanced views (10)	2.0	10.0	6.77	1.85
	Creative expressions (10)	2.0	10.0	7.02	2.48
	Virtual reality functions (10)	2.0	10.0	6.53	2.05
	Total (60)	16.0	58.0	40.39	10.92

4.3. Correlations

As shown in Table 9, we analyzed the correlations between the students' posttest scores on CPS and the scores of the artifact produced during the learning process (i.e., essay and VR work scores). The reason for conducting the correlation analysis was to examine how CPS perceived by individual students is related to the output produced at the individual level (essay) and the group level (VR work). Regarding the relationship between CPS and essay scores, statistically significant correlations exist among all variables, except the relationship between higher-order thinking and judgment. The highest correlation was found in the relationship between divergent thinking and the description ($r = .213$, $p < .05$). We also conducted a correlation analysis between the students' posttest scores on CPS and their scores on the VR work. Only one statistically significant correlation was found among these variables, which was different from the trend observed in the correlation with the essay scores. The only significant correlation was between creative expressions and divergent thinking ($r = .175$, $p < .05$).

Table 9. Correlations between CPS, essay, and VR work scores

	Creative problem solving (CPS)			
		Higher-order thinking	Divergent thinking	Problem-solving skills
Art criticism essay	Description	.185*	.213*	.184*
	Formal analysis	.186*	.193*	.171*
	Interpretation	.203*	.170*	.205*
	Judgment	.160	.185*	.210*
VR work	Application of aesthetic and contextual knowledge	-.004	.089	-.006
	Use of researched materials	.019	.079	-.022
	Originality and balanced views	-.053	.101	-.028
	Creative expressions	.011	.175*	.021
	Virtual reality functions	-.003	.119	-.019

Note. *$p < .05$.

5. Discussion and conclusion

5.1. Discussion of key findings

In this study, we examined the effect of engaging students in SEA education to introduce authentic contexts for learning and fostering CPS skills beyond well-known solutions. In particular, we engaged 135 high school students in Korea in creating 3D virtual worlds as an interpretive and expressive space to represent their solutions in an immersive VR platform. This section revisits the three research questions that guided the present study and discusses the implications.

Regarding the first research question, the changes in CPS scores measured in the pretest and posttest were statistically significant, indicating that the students improved their ability to creatively solve problems significantly after participating in the SEA program. This finding is consistent with the existing SEA research in art education that has reported positive effects on students' learning outcomes (e.g., Chung & Li, 2020; Roberts et al., 2008). We attribute this positive effect to the intentional design of the SEA activities, which aims to promote students' CPS skills in four inter-related stages. The learning activities in each stage were designed following the framework of authentic learning environments (Herrington & Oliver, 2000). Such intentional design also guided the students to navigate between the problem space and the solution space during the problem-solving process. In particular, the SEA program highly emphasized building empathy concerning various social problems by appreciating and discussing the meaning of artworks. One of the core implications of authentic learning is that when learning is decontextualized from students' daily life, students have difficulty building empathy concerning social issues and tend to believe that knowledge is distant from their lives (Anderson et al., 1996). The first stage in the SEA program provided students with an opportunity to see the relevance of various social issues to their personal lives. Further, the group discussion and class debate provided a platform where the students unpacked the meaning of the artwork from more critical stances. With a sufficient discussion regarding how serious and important each social problem is, students could extend their thinking with relevance and empathy, which are important attributes of designer ways of knowing (Cross, 2007).

The second research question examined how CPS skills are expressed in the concrete artifacts (i.e., essay and VR work) that students created. Adopting the co-evolution framework by Maher et al. (1996), we used the comprehensive rubric to examine students' CPS in the problem-space dimension captured as process narratives in writing and their CPS in the solution space captured as a visualized expression in VR work. The evaluation indicates that the mean of the art criticism essays was 33.23 (*SD* = 10.39) out of 50 whereas the mean of the VR work was 40.37(*SD* = 10.92) out of 60. The scores were not as high as we expected. The standard deviations were also rather high, indicating that the levels of the student artifacts were diverse. We speculate that the essay scores were influenced by the individual students' critical and analytical writing abilities. While the essay template included statements about what each element of the art criticism model requires, art criticism is a challenging activity even for university students majoring in art (Wolff & Geahigan, 1997). The finding implies that students may need more scaffolding to perform critical and analytical writing, especially for those who received low scores on the essay. Concerning the evaluation of the VR work, the results show a rather high standard deviation indicating group differences. Given that this was the first implementation of the SEA program with VR, the finding suggest that the students may need more exposure and experience to transfer CPS skills to a virtual platform.

In the last research question, we intended to examine whether any statistically significant relationships exist between the CPS skills and the artifact produced during the learning process (i.e., essay and VR work scores). The overall results indicate that the CPS skills had significant relationships with the essay scores except for one relationship, whereas only one significant relationship exists between the CPS skills and VR work. Our finding is rather different from the previous study such as Chang et al. (2020) and Hu-Au and Lee (2017) that found positive effects of VR on the creative design process and outcomes. We interpreted the different results from the perspective of individual and group creativity. While both the CPS skills and essays were measured at the individual level, the VR work was measured at the group level. The literature suggests that individual creativity and group creativity should be understood as different entities (Sawyer, 2010). That is, group creativity cannot be reducible to individual-level explanations. Likewise, the paradigm of knowledge creation has suggested that a group is more than the sum of individuals, emphasizing the power of collective intelligence (Bereiter & Scardamalia, 2014; van Aalst, 2009). Individual CPS skills may be limited in the VR production due to group dynamics. However, the significant relationship between creative expressions in the VR work and the individual students' divergent thinking implies some association between individual creativity and group creativity. This finding suggests the need to scaffold the CPS process at a group level so that individual students in a group could express their creative ideas freely to create synergy for the final solutions. About the affordances of VR, it is encouraging to see the significant relationship between creative expressions and divergent thinking. This may imply the importance of the 3D VR platform as a space to express creative ideas in divergent ways, which is rather limited in paper-based or 2D platforms.

5.2. Limitations and areas for future research

Some limitations of this study include the following. First, this study measured individual creativity but not group-level creativity. Because the VR production was done in groups, it would be useful for future research to examine how group creativity unfolds in the CPS process. Future research can employ discourse analysis, which has been used in the existing literature on designers' discussions (e.g., Dorst & Cross, 2001), to unpack the nature of group creativity. Second, the generalization of the findings should be limited to a similar research context and student profiles. Since the study was conducted at a boys' high school, future research needs to examine whether similar findings can be obtained with female students. In addition, future implementations need to consider students' technology competency for VR content production. While CoSpaces Edu is a user-friendly program for creating 3D virtual worlds, learners with little or no programming skills may need additional technical training. Third, the present study did not compare the effect of the SEA with VR to other approaches due to the school policy. We suggest that future research needs to conduct an experimental study with a control group that uses a traditional approach without the support of advanced technologies like VR. Lastly, this research focused on the cognitive aspect of creativity within problem-solving situations and did not consider affective dimensions of creativity. One of the promising areas for future research is to investigate the interplay of cognitive and affective dimensions of CPS with the consideration of students' affective attributes such as curiosity, openness, sensitivity, and persistence.

Although SEA has received much attention as a new direction for art education, scarce empirical research has examined how SEA programs affect students' creative learning. The present study supports that engaging students in solving authentic social problems through VR creation is a promising approach to facilitating students' CPS skills. The study findings also provide insight into the importance of engaging students in creating social values through VR beyond simply consuming VR content. We hope this study can provoke more research interest in the influence of socially engaged practices in other disciplines.

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