Influences of Online Synchronous VR Co-Creation on Behavioral Patterns and Motivation in Knowledge Co-Construction

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ABSTRACT: To explore knowledge co-construction patterns and learning motivation within virtual EFL co-creation environments, this study examined behavioral patterns and motivation in three different co-creation environments (paper-based, 2D digital, and 3D VR co-creation) through sequential behavioral analysis and ANCOVA. The study utilized a quasi-experimental research design with a total of 66 tenth-grade students from two English classes at a public senior high school in northern Taiwan. Based on the visualized behavior transition diagrams, the task-switching behaviors between dissonance identification and knowledge negotiation as well as the isolated behaviors of applying newly-constructed knowledge are the core of knowledge co-construction. Particularly, 3D VR co-creation was characterized by the highest number of higher level isolated acts and lower level circular continuity, both of which reflect VR co-creators' efforts to gain familiarity with advanced technology as well as the intention to exchange information and reach community consensus to overcome task complexity, form community consensus, and lower anxiety. Such behavioral patterns echoed the results of ANCOVA on intrinsic and extrinsic motivation; that is, on either intrinsic or extrinsic motivation, the influence of 3D VR co-creation was the greatest, followed by that of 2D digital co-creation and paper-based co-creation. For future co-creation instruction and research, it is suggested that the instruction of VR co-creation be invested with abundant time to allow mature higher level knowledge co-construction dialogues to occur. Moreover, to gain an even deeper understanding of the social structure embedded in knowledge co-creation, it is suggested that social network analysis (SNA) be employed in future research.

Keywords: Behavioral patterns, Intrinsic motivation, Extrinsic motivation, Co-creation, Virtual Reality

1. Introduction

Social constructivism holds that knowledge is co-created and co-constructed (Mayer, 1996). In this sense, meanings are co-constructed from individuals' jointly-constructed understandings of the world and hence are historically situated in cultural values and practices. With societal contexts and interpersonal relationships constantly shifting, such contextually constructed coordination among people mostly through languages is never fixed and isolated (Camargo-Borges & Rasera, 2013; Gergen & Gergen, 2004); instead, it is fluid, transitory, and dynamic in nature.

Dialogue, creativity and, co-creation may best characterize the post-industrial, social constructivist civilization, where shaping and reshaping meanings and value are not limited to the authorities. Co-creation particularly features today's "network society," where relationship-dominant practice brings co-creativity and conversation for shared leadership and higher equity. Also, it constructs knowledge for common interests or an even higher inter-personal purpose (Camargo-Borges & Rasera, 2013). This generative, participatory fashion later brought about the "learner-as-partner" practice in educational co-creation and knowledge co-construction in the United States, Canada, the United Kingdom, Australia, and Scandinavia (Bovill, 2019).

In the field of education, motivation, defined as the desire to be competent and self-determining in relation to the environment (Deci & Ryan, 1980), is believed to be associated with the four components in learning activities: challenge, curiosity, control, and fantasy (Lepper & Hodell, 1989). Virtual reality (VR), featuring presence, interactivity, and immersion, provides learners with stimuli for make-believe fantasy and curiosity and thus may serve to trigger learners' motivation (Huang et al., 2020; Keller, 2010; Lin et al., 2019; Pintrich, 2003), especially the motivation of foreign language (FL) learners (Lan, 2014).

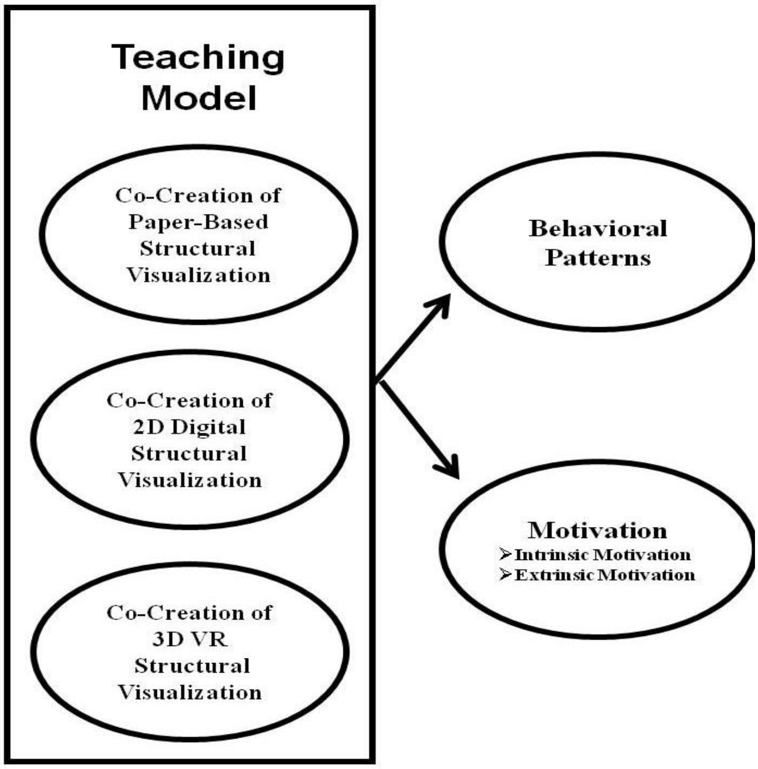
VR co-creation, the practice of turning the abstract into the concrete through collective consciousness and intelligence in synchronous VR coworking spaces, may further integrate learners' curiosity and a strong sense of community into make-believe activities. Such knowledge co-construction practices may advance to help moderate task difficulty, instead of overwhelming individual students, through learners' improved collaborative work and learning skills (Blau & Shamir-Inbal, 2017; Bovill et al., 2011; Giner & Peralt Rillo, 2016; Jans et al., 2017) and greater creativity, better communication, and positive group dynamics (Brandt et al., 2008).

Although abundant studies have examined learners' motivation and learning effects in VR, few have visualized the learning paths of language learners in a virtual world (Hsiao et al., 2017). Even fewer have explored the characteristics of students' behavioral patterns and the association between learners' behavioral patterns and their motivation within virtual co-creation environments in an EFL setting. To fill this gap, this study aimed to investigate learners' behavioral patterns and motivation emerging in online synchronous VR co-creation in EFL classrooms in the hope of unveiling and visualizing learners' behavioral sequences and co-creation strategies to better the "learner-as-partner" practice in educational knowledge co-construction. The research model of this study is shown in Figure 1.

To fulfill the abovementioned research objectives, this study addressed the following research questions:

- What are the differences among the sequential behavior patterns in traditional paper-based co-creation, 2D digital co-creation, and 3D VR co-creation for structure visualization?
- What are the differences in motivation among students engaged in traditional paper-based co-creation, 2D digital co-creation, and 3D VR co-creation for structure visualization?

Figure 1. Research model



2. Literature review

2.1. Virtual Reality

VR engages the audience in an immersive, all-inclusive, sensory illusion with presence, interactivity, and immersion (Biocca & Delaney, 1995; Jarvis, 2019). Over the years, VR has been employed in the fields of entertainment (Schlacht et al., 2017), mental health (Maples-Keller et al., 2017), and education (Moro et al., 2017), especially for learning in abstract environments (Thornhill-Miller & Dupont, 2016). For example, Lamb (2014) indicated that VR helps learners not only conceptualize abstract environments that they have never experienced due to physical and technological limitations, but also activate cognitive attributes. Following this thread, Freina and Ott (2015) suggested the effect of the encapsulated stimuli of VR on learners' enhanced retention and efficacy for novel information through interactive life-like experiences. Krokos et al. (2018) also stated that students with VR experiences retain more information and can better apply newly learned knowledge than those without such experiences.

2.2. Learner motivation in VR

Motivation as one of the indispensable components of goal-directed activities shows positive correlations with learners' achievements (Schunk, 2008). According to Lepper et al. (2005), motivation is categorized into intrinsic and extrinsic motivation; the former refers to the motivation of engaging in one activity for its own sake due to its inherently interesting and enjoyable nature, whereas the latter impels individuals to become involved for explicit outcomes or avoidance of failure and punishment. To assess learners' motivation, numerous studies have employed various educational technologies, such as clicker technology and mobile polling (Sun, 2014), integrated concept maps and classroom polling systems (Sun, et al., 2018a), challenging games (Sun, 2018) and gamified interactive response system (IRS) (Sun & Hsieh, 2018) in their curriculum designs. Moreover, numerous researchers have targeted the association of motivation and learners' behavioral patterns via lag sequential analysis. For example, Sun et al. (2017) found that game-based learning triggered learners' persistent "learning with gaming" behavioral pattern for better knowledge retention. Sun, et al. (2018a) examined the behavioral sequences in a votable concept mapping approach. Also, Sun, et al. (2018b) explored highly motivated students' serious reading patterns and suggested that online reading duration is a significant indicator of online reading motivation.

Further, many studies have claimed the positive relationship between intrinsic motivation and VR (Keller, 2010; Lin et al., 2019). For example, Dalgarno and Lee (2010) observed that spatial knowledge was enhanced and intrinsic motivation increased due to the contextualization of VR. Lin et al. (2019) examined students' situational interest in VR-guide and map-guide groups, indicating the impact of VR guidance on yielding situational interest and motivation. Similarly, Huang et al. (2020) and Linnenbrink and Pintrich (2019) stated that VR presents strong situativity to stimulate learners' intrinsic motivation as well as attention to learning.

2.3. Digital co-creation of VR

Co-creation, different from collaboration, refers to collective wisdom and efforts invested by professionals and nonprofessionals coexisting in communities without clearly specified accountability or leadership duties. Recent studies have shown positive relationships between co-creation and learners' self-awareness of their learning progress and subject knowledge (Elsharnouby, 2015; Lubicz-Nawrocka, 2018), improved collaborative work and learning skills (Blau & Shamir-Inbal, 2017; Jans et al., 2017), increased satisfaction, trust, and loyalty to groups (Blau & Shamir-Inbal, 2017; Giner & Peralt Rillo, 2016), and greater creativity, better communication and positive group dynamics (Brandt et al., 2008). Many studies have particularly indicated the influential impacts of equity commonly shared in digital co-creation on students' learning enthusiasm and motivation (Bovill, 2019; Yilmaz et al., 2020), yet potentially accompanied by inefficiency owing to the higher need for negotiation and compromise (Wang & Sun, 2021; Yilmaz et al., 2020).

VR creation, from the perspective of social constructivism, stimulates collaboration and situativity in knowledge development through diversified and authentic contexts. For example, Grover et al. (2015) indicated the benefits of VR creation for facilitating critical thinking and problem-solving during VR collaborative creation. Castaneda et al. (2017) stressed the contribution of VR creation to meeting learners' diversified learning needs. Yeh et al. (2018) further determined elementary school students' enhanced autonomy and gender differences in collaborative VR creation of authentic contexts. Particularly, Lan (2014) further indicated how VR facilitated effective foreign language (FL) learning through immersion, interaction, and authenticity. Broadbent and Poon (2015) conducted a content analysis to investigate the state of VR and the learning gains in the VR-supported language learning process. Hsiao et al. (2017) explored the learning strategies and approaches used in a virtual world via visualization analytics. Unveiling the learning benefits VR might bring, Koch et al. (2018) yet further indicated the necessity of extending course duration for co-creators to overcome the novelty effect for improved performances and opportunities to challenge higher levels of knowledge co-construction and co-production.

Given an even higher degree of equity and flexibility in task accountability, VR co-creation has further encouraged collective consciousness among learners in web-based real-time co-working platforms. For example, Google CoSpaces Edu is equipped with a user-friendly interface and coauthoring tools for VR co-creators to simultaneously co-edit texts and co-create VR scenes within a virtual environment. Moreover, its coding feature equips learners with little or no programming skills to visualize the abstract by programming self-created objects to follow instructions. GmbH (2017) considered CoSpaces a complement to traditional teaching methods by immersing students in a VR world where coding can be connected with the curriculum on a completely new level. Recent studies (Bertolini et al., 2018; Krause, 2017) have also shown positive learning outcomes of Google CoSpaces Edu in primary and secondary education; students using CoSpaces for digital storytelling to co-create virtual art exhibitions (Bertolini et al., 2018) and historical scenes (Krause, 2017) had better comprehension and retention of subject-matter knowledge.

Ideally expected to stimulate autonomy, collaboration, and cognitive learning, the question of whether 3D VR co-creation consists of distinct knowledge construction behavior remains unexplored. To be more specific, little research has examined real-time VR co-creation in terms of sequential behavioral patterns and motivation in an EFL setting. To fill the gap, this study explored learners' collective intelligence and consciousness from the perspective of behavioral patterns and motivation in a VR co-creation project in EFL classrooms.

3. Methods

The study explored learners' behavioral patterns and assessed their motivation in a VR co-creation project in EFL classrooms. To achieve these objectives, information about the participants, methods, instructional design, and study instruments, an overview of the co-creation platforms, and the data collection and analysis procedures are provided and illustrated in the following sections.

3.1. Participants

This quasi-experimental research was conducted in 2021 and involved one teacher and a total of 66 10th-grade students, including 39 males (59%) and 27 females (41%) from two English classes at a public senior high school in northern Taiwan. The average age of the students was 16.47 years (*SD* = .56). To assess the effects of the paper-based, 2D Jamboard, and VR CoSpaces environments on co-creation, the participants were randomly assigned to a control group, experimental group A, and experimental group B, with a valid sample of *n* = 22 in each group. It is noteworthy that the subgroup gender was not as balanced as the overall student body, as shown in Table 1, due to the random sampling policy, which was used to help create an authentic context of co-creation in the classrooms.

Table 1. The gender ratio of the three subgroups

	Male (34 students)	Female (32 students)
Paper-based Co-creation (22 students)	7 (32%)	15 (68%)
2D Jamboard Co-creation (22 students)	11 (50%)	11 (50%)
3D VR CoSpaces Co-creation (22 students)	16 (73%)	6 (27%)

3.2. Methods and instructional design

The experimental process of this study is shown in Figure 2. Session 1 (100 minutes) involved a pre-test on intrinsic and extrinsic motivation, along with the training on tool use and the reading strategies for the two genres, namely descriptive narratives and expository announcement, through which the students were introduced to Kinkaku-ji in Kyoto during the COVID-19 pandemic. To be more specific, the descriptive narrative, entitled "Kyoto: The Heart of Japan," was required to be rewritten with reference to the expository announcement, entitled "Sightseeing Facilities in Japan Reopening with Preventative Measures for COVID-19." To meet the goal, several comprehension strategies for long passage reading such as scanning, skimming, and graphic organizers were taught to organize and visualize ideas, which, based on Lan (2013), may facilitate vocabulary learning while reading.

Session 2 (200 minutes) was the phase of co-creation, where the student co-creators were engaged in the idea visualization tasks for the abovementioned genre reading and writing mission; the control group was engaged in paper-based co-creation, while experimental groups A and B used Google Jamboard and CoSpaces for digital 2D and 3D VR co-creation, respectively (see Figure 3). The process of co-creation was video- and screen-recorded for the sequential behavioral analysis. The experiment ended in Session 3 with post-tests on intrinsic and extrinsic motivation.

Figure 2. The experimental flow

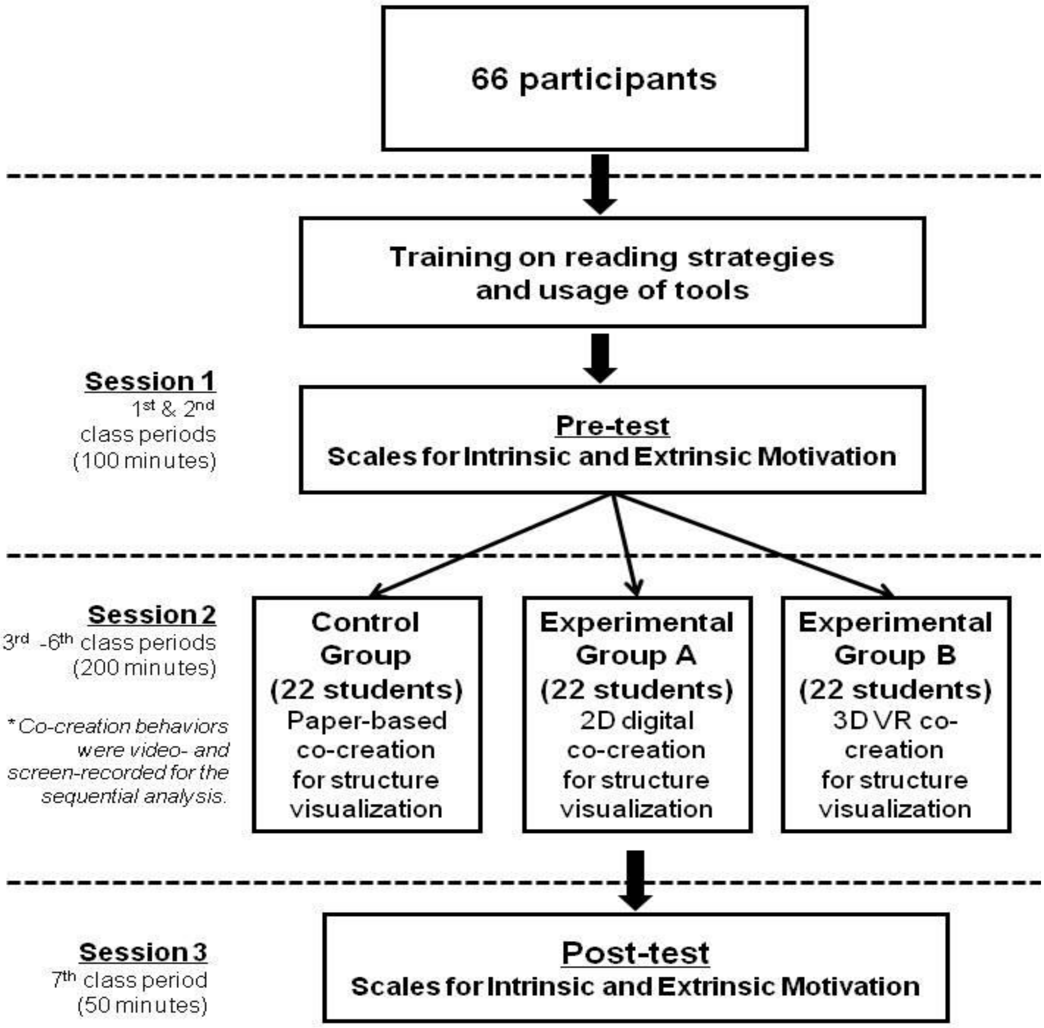
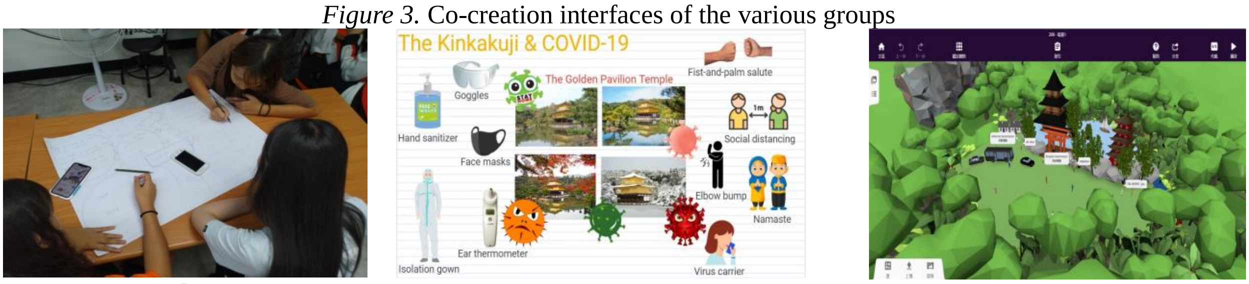


Figure 3. Co-creation interfaces of the various groups



Control Group | Experimental Group A | Experimental Group B

3.3. Instruments

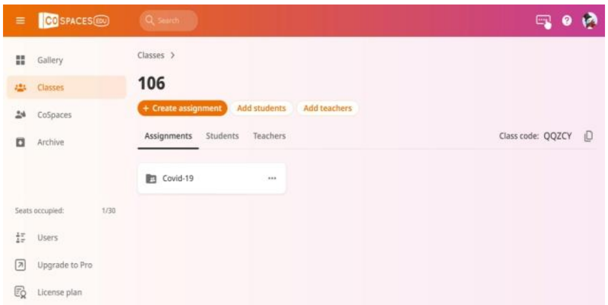
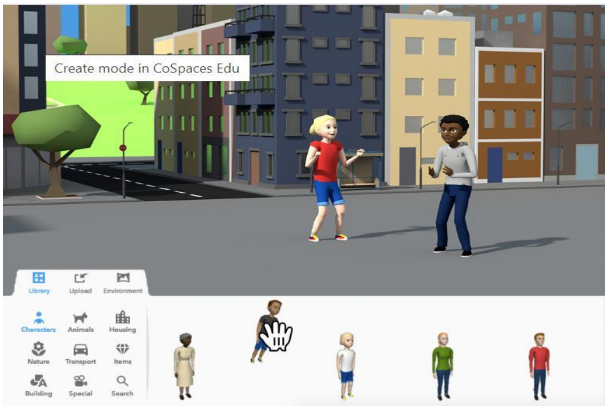
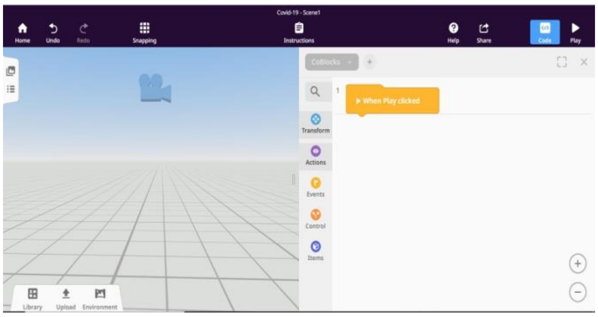
The scale assessing motivation, which was based on the scale of Pintrich et al. (1991), with reference to that of Sun and Hsieh (2018), was a 6-point Likert scale with four questions on intrinsic motivation and four questions on extrinsic motivation. An example question for intrinsic motivation is, "In a class like this, I prefer course material that challenges me so I can learn new things." An example question for extrinsic motivation is, "Getting a good grade in this class is the most satisfying thing for me right now." In terms of the reliability of the post-test, the Cronbach's alpha value for the scale was .94, while the reliability values of the constructs ranged from .89–.94, indicating excellent overall internal consistency (George & Mallery, 2003).

3.4. Digital co-creation platforms: Google Jamboard and CoSpaces

The digital co-creation platforms were Google Jamboard and CoSpaces. The former was used for 2D structure visualization co-creation, whereas the latter functioned as a co-working space for learners to create context-based simulated scenarios that could be explored virtually using cardboard headsets. Both Google Jamboard and CoSpaces can be co-authored, allowing users to simultaneously co-edit texts and co-create objects and scenes within a virtual environment. Particularly, CoSpaces enables users to create 3D VR scenarios for use as backgrounds. Learners may further make objects interactive through Scratch-like coding within CoSpaces. The features of Google CoSpaces Edu are listed and illustrated in Figure 4.

After co-designing, co-constructing, and co-coding their virtual worlds, students can explore them using a Google Cardboard headset or similar VR viewers. Finally, users may share their fully immersive worlds with others via a link or QR code.

Figure 4. Features of Google CoSpaces

Feature	Description	Illustration
Dashboard	On the dashboard are the gallery and the control panel for assigning students to groups.	
Creation Toolbox	The creation toolbox includes assets and buildings for creative co-creation.	
Coding Features	Brick-like coding for the programming of characters/objects to follow instructions.	

3.5. Data collection and analysis

A large amount of video-based data was used for the sequential analyses. Firstly, the entire process, involving a total of 66 students and more than 150 hours of video data, was screen- and video-recorded. Secondly, the recorded co-creation behaviors were chronologically coded in 5-second slots based on the coding scheme of Social Construction of Knowledge (see Table 2), based on the Interaction Analysis Model (IAM) proposed by Gunawardena et al. (1997) to qualitatively examine types of cognitive activities performed by co-creators through their behaviors of questioning, clarifying, negotiating, and synthesizing during co-creation.

Two skilled coders with educational backgrounds were recruited to ensure the consistency, reliability, and validity of the data. To examine the reliability of the data, the complete video data of one sampled student was firstly encoded in the pilot study by both coders. The analysis revealed the reliability of the Multi-rater Fleiss Kappa coefficient k to be .63, which achieved good consistency (Landis & Koch, 1977). Finally, a total of 94,776 behavioral codes were yielded.

Table 2. Interaction analysis model for examining knowledge construction in co-creation activities

Coding	Behavior	Definition	Examples
C1	Comparing of Information	A statement of observation or opinion	Co-creators sharing observations and opinions.
		A statement of agreement from one or more other participants	Co-creators agreeing with each other.
		Corroborating examples provided by one or more participants	Co-creators supporting each other by strengthening provided examples.
		Asking and answering questions to clarify details of statements	Co-creators asking and answering each other to gain a deeper understanding.
		Definition, description, or identification of a problem	Co-creators providing definitions, descriptions, or identification of a problem.
C2	The Discovery and Exploration of Dissonance or Inconsistency Among Ideas, Concepts or Statements	Identifying and stating areas of disagreement	Co-creators indicating cognitive incongruity.
		Asking and answering questions to clarify the source and extent of disagreement	Students asking and answering each other to identify cognitive dissonance.
		Restating the participant’s position, and possibly advancing arguments or considerations in its support by references to the participant’s experiences, literature, formal data collected, or proposal of relevant metaphors or analogies to illustrate points of view	Co-creators strengthening statements with further information or data, whether formal or not.
C3	Negotiation of Meaning/Co-Construction of Knowledge	Negotiation or clarification of the meaning of terms	Co-creators clarifying or negotiating over confusing expressions.
		Identification of areas of argument or overlap among conflicting concepts	Co-creators comparing and contrasting concepts.
		Proposal and negotiation of new statements embodying compromise and co-construction.	Co-creators proposing and negotiating over new ideas.
		Proposal of integrating or accommodating metaphors or analogies	Co-creators proposing to integrate and accommodate metaphors or analogies.
		Testing the proposed synthesis against “received fact” as shared by the participants and/or their culture	Co-creators challenging the “received fact.”
C4	Testing and Modification of Proposed Synthesis or Co-Construction	Testing against an existing cognitive schema	Co-creators testing a new method against an existing cognitive schema.
		Testing against personal experience	Co-creators testing a new method against personal experience.
		Testing against formal collected data.	Co-creators testing a new

			method against formal collected data.
		Testing against contradictory testimony in the literature	Co-creators testing a new method against existing literature.
		Summarization of agreement(s)	Co-creators summarizing consensus.
C5	Agreement Statement(s)/Applications of Newly-Constructed Meaning	Application of new knowledge	Co-creators applying their co-constructed knowledge.
		Meta-cognitive statement by the participants illustrating their understanding that their knowledge or ways of thinking (cognitive scheme) have changed as a result of the conference interaction	Co-creators expressing their changed understanding after knowledge co-construction.

4. Results and discussion

To answer the first research question on the sequential behavioral patterns in the various co-creation environments, the data coded based on the Interaction Analysis Model (IAM) proposed by Gunawardena et al. (1997) underwent sequential analysis. Firstly, the adjusted residuals tables of the three groups as shown in Tables 3, 4, and 5 were generated and are elucidated in the following sections. The z-score values were calculated to determine the continuity of each sequence; as Bakeman and Gottman (1997) indicated, a z-score greater than +1.96 implies the significance ($p < 0.05$) of a sequence. Based on the z-score values, the diagrams of the behavioral transition patterns were visualized, as shown in Figures 5, 6, and 7.

To answer the second research question on motivation in the three co-creation environments, the analysis of covariance (ANCOVA) in SPSS 20 was performed to identify between-group differences, with the pre-test as the covariant, the post-test as the dependent variable, and the co-creation mode as the fixed factor.

4.1. The sequential patterns of the paper-based co-creation

The adjusted residuals of the behavioral transition patterns in paper-based co-creation are presented in Table 3. The z-score values were visualized in the transition diagram, as shown in Figure 5, where the arrows disclosed the directions of the seven sets of significant sequences, including isolated continuity (C1→C1 and C5→C5), unidirectional movements (C4→C2) and bidirectional movements (C2↔C3 and C3↔C4).

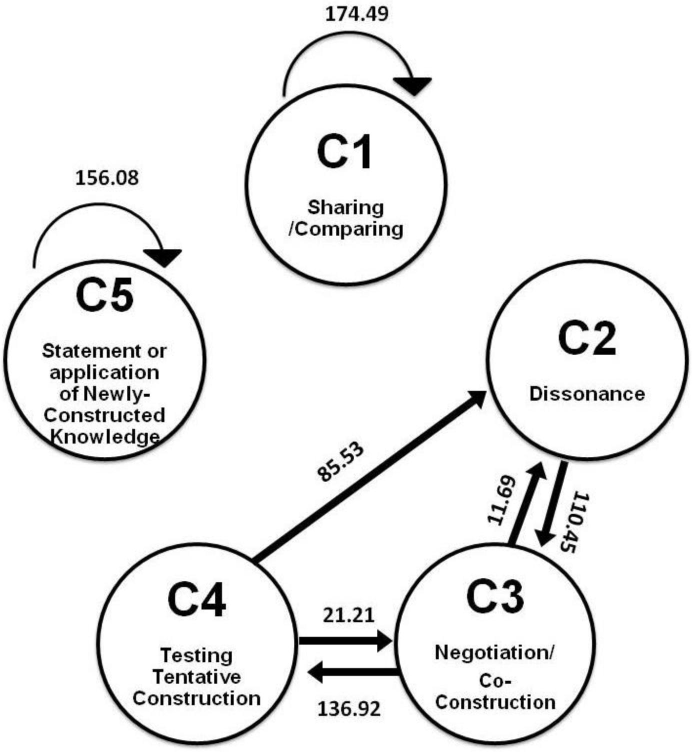
It is noteworthy that both the isolated continuity of C1→C1 and C5→C5 reached a high level of significance; the former reached the z-score value of 174.49 ($p < .05$) while that of the latter was 156.08 ($p < .05$). As for the bidirectional continuity, the z-score values of the forward movements from C2 to C3 ($z = 110.45$, $p < .05$) and from C3 to C4 ($z = 136.92$, $p < .05$) showed greater significance than those of the backward movements from C3 to C2 ($z = 11.69$, $p < .05$) and from C4 to C3 ($z = 21.21$, $p < .05$). Furthermore, only one unidirectional sequence of C4→C2 was discovered ($z = 85.53$, $p < .05$), with which learners in paper-based co-creation made it possible to form a recurring cycle across C2, C3, and C4. Throughout such a circular behavioral cycle, paper-based co-creators might frequently and repeatedly identify disagreement, co-construct knowledge, and test tentative knowledge structures.

Table 3. The results of sequential analysis of behaviors in the paper-based co-creation

	C1	C2	C3	C4	C5
C1	174.49*	-13.32	-30.58	-23.56	-43.93
C2	-18.66	-22.29	110.45*	-27.63	-51.51
C3	-30.03	11.69*	-12.23	136.92*	-82.89
C4	-23.13	83.53*	21.21*	-34.25	-33.66
C5	-42.87	-51.21	-58.90	-63.48	-42.87

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

Figure 5. Sequential patterns of the paper-based co-creation



4.2. The sequential patterns of the 2D Jamboard Co-Creation

The adjusted residuals of the 2D Jamboard Co-Creation are presented in Table 4, where the z-score values were visualized in the diagram of the behavioral transition patterns, as shown in Figure 6. In this diagram, it is noticed that the arrows disclose the directions of the eight sets of significant sequences, including isolated continuity (C3→C3, C4→C4, and C5→C5), unidirectional movements (C3→C4) and bidirectional movements (C1←→C2 and C2←→C3).

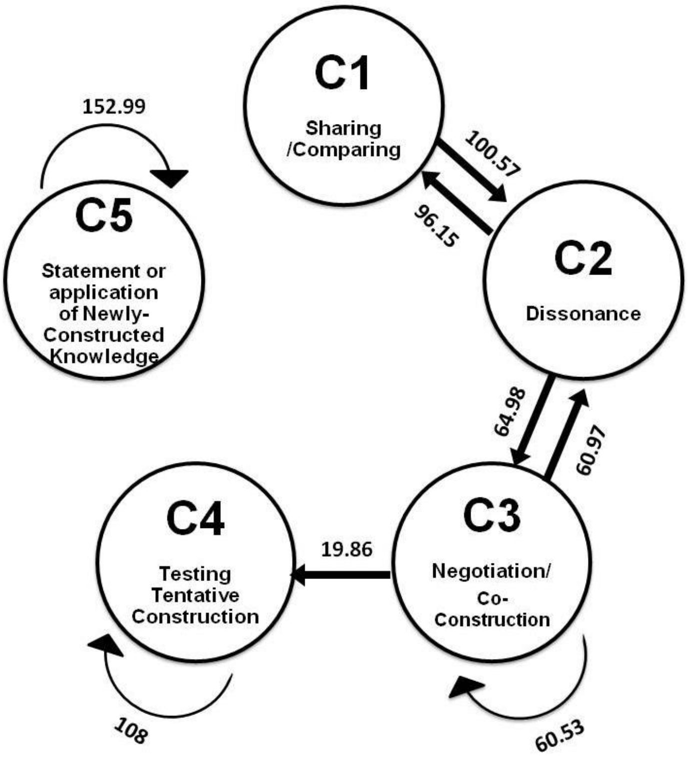
It is noteworthy that the isolated continuity of C5→C5 (z = 152.99, p < .05) and C4→C4 (z = 108, p < .05) showed much higher significance than that of C3→C3 (z = 60.53, p < .05). Moreover, in the bidirectional continuity, the z-score values of the forward movements from C1 to C2 (z = 100.57.45, p < .05) and from C2 to C3 (z = 64.98, p < .05) were rather close to those of the backward movements from C2 to C1 (z = 96.15, p < .05) and from C3 to C2 (z = 60.97, p < .05), which displayed a contrast to the bidirectional movements in paper-based co-creation. Such contrast might result from the digital co-creators' access to abundant online resources and their greater needs for examination and re-examination of the information sent and received if compared with paper-based co-creators working face-to-face on hands-on materials. Furthermore, only one unidirectional sequence of C3→C4 was discovered with a considerably low z-value of 19.86 (p < .05). In short, unlike paper-based co-creation, there existed no frequent task-switching behaviors or circular behavioral cycles beyond C3 in the 2D digital co-creation. Instead, 2D co-creators depended more on specific isolated behaviors and encountered greater challenges of advancing to higher levels of knowledge co-construction, which might potentially cause insufficiency, as indicated by Wang and Sun (2021) and Yilmaz et al. (2020).

Table 4. The results of sequential analysis of behaviors in the 2D Jamboard co-creation

	C1	C2	C3	C4	C5
C1	-5.88	100.57*	-17.70	-13.91	-32.96
C2	96.15*	-19.20	64.98*	-24.58	-58.26
C3	-16.92	60.97*	60.53*	19.86*	-94.91
C4	-13.30	-24.58	-23.41	108.00*	-38.57
C5	-31.34	-57.93	-65.83	-74.17	152.99*

Note. *p < .05.

Figure 6. Sequential patterns of the 2D Jamboard co-creation



4.3. The sequential patterns of the 3D VR Co-Creation

The adjusted residuals of the sequential patterns of the 3D VR co-creation are presented in Table 5. The z-score values were visualized in the diagram of the 3D VR behavioral transition patterns, as shown in Figure 7. In this diagram, it is noticed that the arrows disclose the directions of the eight sets of significant sequences, including isolated continuity (C2→C2, C3→C3, C4→C4, and C5→C5), unidirectional movements (C2→C3 and C3→C1), and bidirectional movements (C1←→C2).

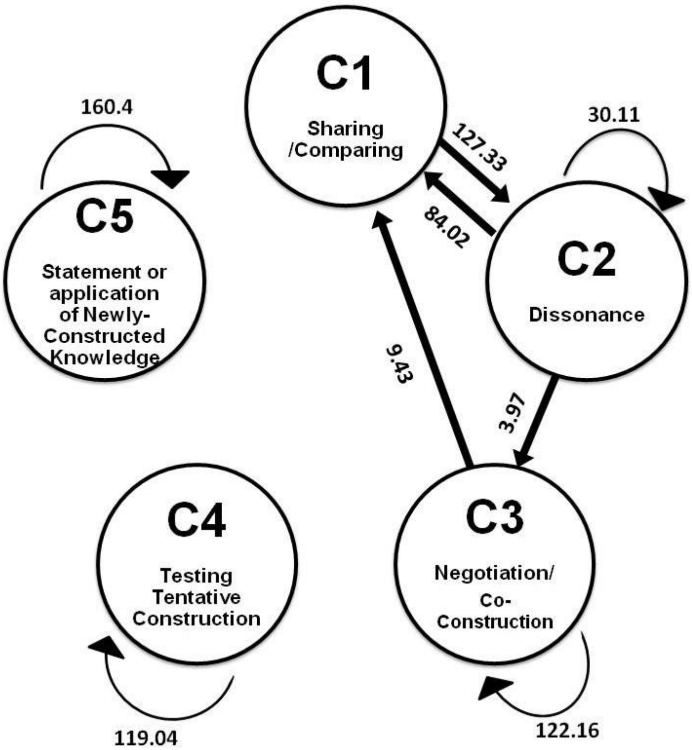
Compared with paper-based and 2D digital co-creation, in 3D VR co-creation there existed the most isolated continuity and the least number of bidirectional movements. Specifically, isolated continuity included C5→C5 (z = 160.4, $p < .05$), C4→C4 (z = 119.04, $p < .05$), C3→C3 (z = 122.16, $p < .05$), and C2→C2 (z = 30.11, $p < .05$), whereas bidirectional continuity fell on C1←→C2 with z-values of 127.33 and 84.02 ($p < .05$). Furthermore, two comparatively weak unidirectional sequences of C2→C3 (z = 3.97, $p < .05$) and C3→C1 (z = 9.43, $p < .05$) were discovered to form a circular behavioral pattern across C1, C2, and C3. These findings in VR co-creation support the novelty effect whereby the more advanced technology is, the more efforts co-creators have to exert on specific isolated behaviors, by which they attempt to improve their performance and to challenge higher levels of knowledge co-construction and co-production (Koch et al., 2018).

Table 5. The results of sequential analysis of behaviors in the 3D VR co-creation

	C1	C2	C3	C4	C5
C1	-27.10	127.33*	-34.97	-26.43	-47.02
C2	84.02*	30.11*	3.97*	-36.90	-65.63
C3	9.43*	-48.82	122.16*	-11.30	-59.95
C4	-26.12	-19.17	-33.70	119.04*	-19.49
C5	-46.15	-65.21	-59.56	-22.37	160.40*

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

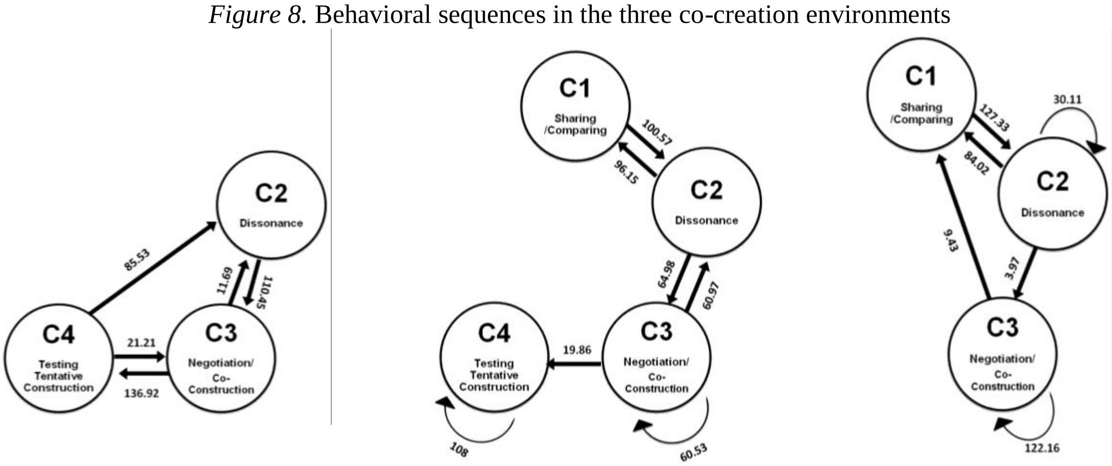
Figure 7. Sequential patterns of the 3D VR co-creation



4.4. Associations between co-creation environments and knowledge construction behaviors

Figures 8 and 9 highlight the behavioral sequences and isolated behavior contiguity in the three various co-creation groups.

Figure 8. Behavioral sequences in the three co-creation environments



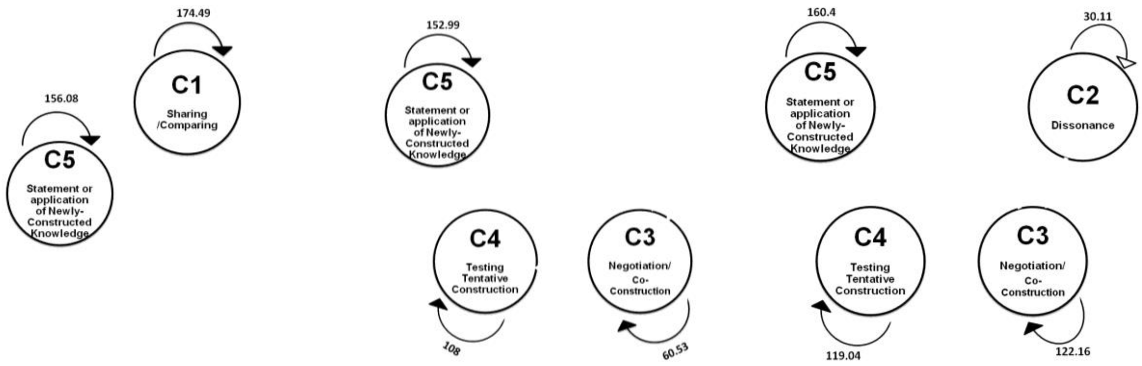
Control Group (Paper-based)	Experimental Group A (2D Jamboard)	Experimental Group B (3D VR CoSpaces)

Figure 8 is the visualized diagram highlighting the chained behaviors in the paper-based, 2D digital, and 3D VR groups. The commonality among the three is the sequence of C2→C3, suggesting that the behavioral movement from dissonance identification to meaning negotiation is the core of knowledge co-construction. On the other hand, it is noteworthy that the pattern between C2 and C3 distinguished the 2D and 3D VR co-creation behaviors. To be more specific, in 2D digital co-creation, C2→C3 was paired with C3→C2 to form bidirectional movements, whereas in VR co-creation there existed the unidirectional sequence of C2→C3 with a weak p-value; yet it was accompanied by strong but isolated continuity of C2 and C3. In other words, VR co-creators were stuck in repeated isolated behaviors (e.g., dissonance identification, knowledge negotiation) in the hope of reaching consensus with peers and gaining familiarity with the new technology, which, as Koch et al. (2018)

indicated, does indeed reflect the novelty effect of new technology and may, in turn, bring about the learners' persistence in specific isolated learning behaviors.

Additionally, the circular chained sequences of behavioral movements were observed in VR co-creation, but not in 2D digital co-creation. This indicates that the learners in the VR co-creation mode tended to return to the lower knowledge co-construction levels from the higher-level ones. Moreover, VR co-creators' stronger dependence on information sharing and comparing (C1) and greater difficulty in advancing to testing tentative knowledge structures (C4) due to the higher complexity of VR co-creation further distinguished their circular sequences from those of 2D digital co-creators.

Figure 9. Isolated continuity in the three co-creation environments



Control Group (Paper-and-pen) | Experimental Group A (2D Jamboard) | Experimental Group B (3D VR CoSpaces)

Figure 9 highlights the isolated contiguity in co-creation. As shown, the co-creators in the three different environments all showed fervent effort in C5, indicating learners' great motivation to apply newly constructed knowledge for task completion no matter which co-creation group they belonged to.

Moreover, it should be noted that in VR co-creation there existed the highest number of instances of isolated continuity, manifesting a great contrast to the least number in paper-based co-creation. On the other hand, the isolated C2 and C3 continuity featured not only VR co-creators' persistent needs for information sharing but stronger eagerness for cognitive dissonance resolution, if compared with those of the 2D digital co-creators. These support the previously mentioned claim that VR co-creators tended to repeat specific isolated behaviors to gain familiarity with new technology. Also, owing to the complexity of digital tool use, VR co-creators depended more on basic knowledge co-construction acts and encountered greater obstacles in advancing to higher hierarchical behaviors. Both the findings echoed the claim of Koch et al. (2018) that the novelty effect leads to higher motivation to perform particular isolated behaviors to get better control over new technology and to improve performance.

4.5. Motivation in different co-creation environments

ANCOVA in SPSS 20 was performed for student motivation to identify between-group differences, with the pre-test as the covariant, the post-test as the dependent variable, and the co-creation mode as the fixed factor. With the insignificant result of the homogeneity test, the ANCOVA results showed that the effect of interaction between the covariates and variables was significant (F = 1823.06, p < .00), as was the effect of the co-creation environments on student motivation (F = 2409.31, p < .00).

Table 6. Summary of covariance analysis for motivation

Source of variance	*SS*	*df*	*MS*	*F*	*p*	Partial η^2
Covariates (pre-test on motivation)	30.86	1	30.86	1823.06	.00	96.7%
Inter-group (co-creation platforms)	81.58	2	40.79	2409.31	.00	98.7%
Intra-group (Error)	1.06	62	.02			
Overall	1019.82	66				

As shown in Table 6, the effects of the pre-test and the co-creation platforms were significant on the learners' overall motivation. Specifically, the covariate significantly predicted the dependent variable (F = 1823.06, p

< .00), suggesting that the post-test on motivation was influenced by the pre-test. Moreover, with the pre-test effect removed, the effect of the co-creation environments was still significant (F = 2409.31, p < .00). In other words, the post-test motivation score was influenced by the co-creation environments.

Further ANCOVA results on the two constructs of motivation (intrinsic and extrinsic motivation) are reported in Table 7 below. In terms of intrinsic motivation, the effect of the co-creation environment was significant (F = 1282.06, p < .00). The effect of the co-creation environment was also observed to be significant for extrinsic motivation (F = 1024.57, p < .00). In other words, both the post-test intrinsic and extrinsic scores were influenced by the co-creation environments. Particularly, on either intrinsic or extrinsic motivation, the influence of 3D VR co-creation was greater than that of 2D digital co-creation, and both were greater than that of paper-based co-creation as a means of structure visualization.

Table 7. Summary of the covariance analysis of the constructs of motivation

Constructs	*F*	*p*	Post hoc
Intrinsic Motivation	1282.06	.00	(3) > (2) > (1)
Extrinsic Motivation	1024.57	.00	(3) > (2) > (1)

Note. (1) = Control Group; (2) = Experimental Group A; (3) = Experimental Group B.

4.6. Associations between behavioral patterns and motivation in co-creation environments

Based on the aforementioned findings of the sequential behavioral analysis, the high frequency of C2→C3 and the isolated congruity of C5 among all the groups were noticed, connoting not only the student co-creators' persistent efforts on idea negotiation and structure construction, but also their motivating enthusiasm of completing co-creation tasks whichever co-creation group they belonged to. Such behavioral patterns could be further reflected by the ANCOVA results that the overall motivation was significantly influenced by the various co-creation platforms, which is consistent with the findings of Brandt et al. (2008), Hwang and Chen (2017), Bovill (2019), and Yilmaz et al. (2020) that co-creation with various levels of equity may influence learners' group dynamics and learning motivation.

On the other hand, compared with 2D and paper-based co-creators, the preference of 3D VR co-creators for lower-level task-switching behaviors and isolated higher-level behaviors not only echoed the post-hoc results of ANCOVA that the influence of 3D VR co-creation on either intrinsic or extrinsic motivation was greater than that of 2D digital and of paper-based co-creation, but also explained the two sides of one coin: the avoidance of project failure and uncertainty over advanced technology on one side, and the motivating enthusiasm for visualizing such make-believe fantasy on the other side. While the former manifested 3D VR co-creators' extrinsic motivation as a means of reward or avoidance of failure, the latter highlighted their intrinsic motivation as the driving force to accomplish achievements due to inherent interest or ambition (Schunk, 2008). Such intrinsic motivation, based on Dalgarno and Lee (2010), GmbH (2017), Linnenbrink and Pintrich (2019), and Huang et al. (2020) may particularly result from the highly immersive virtual environment in VR co-creation, and may function as a complement to traditional teaching methods for students to visualize the abstract via co-creativity and knowledge co-construction (Lan, 2020; Lepper et al., 2005; Lepper & Hodell, 1989). Yet, such extrinsic motivation also served as a reminder for instructors to stress the importance of preparatory training on language learning strategies in virtual worlds if learning motivation and outcomes are expected (Lan, 2020).

5. Conclusion and implications

The purpose of this study was to investigate learners' behavioral patterns and motivation of online synchronous VR co-creation in EFL classrooms through sequential behavioral analysis and ANCOVA. Based on the z-score values generated in the sequential analysis, the visualized diagrams of the behavioral transition patterns revealed the fact that the behaviors of dissonance identification and knowledge negotiation were the core of the knowledge co-construction process. Moreover, the persistent isolated behavior of applying newly-constructed knowledge, as shown in every co-creation group, highlighted the learners' enthusiasm and motivation for co-creation, as indicated by Brandt et al. (2008).

The visualized transition diagrams also showed that VR co-creation involved the most isolated behavioral continuity, whereas paper-based co-creation showed the least. This reflected VR co-creators' persistence in repeating isolated learning behaviors to gain higher levels of familiarity with new technology, as Koch et al. (2018) indicated that the novelty effect of new technology may, in turn, bring about the learners' greater motivation on specific learning behaviors. Such uncertainty over advanced technology was also reflected from the low-level circular continuity in VR co-creation; VR co-creators depended on lower-level chained behaviors to exchange information and reach community consensus to overcome the task complexity and to lower the sense of anxiety.

On the other hand, the ANCOVA results revealed the significant influences of the various co-creation environments on motivation. Further ANCOVA results displayed the significant effects of the different co-creation environments on intrinsic and extrinsic motivation. More specifically, on either intrinsic or extrinsic motivation, the influence of 3D VR co-creation was greater than that of 2D digital co-creation, and both were greater than that of paper-based co-creation as a means of structure visualization.

The results of the sequential behavioral analysis and ANCOVA supported what GmbH (2017), Hwang et al. (2017), Linnenbrink and Pintrich (2019), and Huang et al. (2020) claimed, namely that VR co-creation afforded contextualization, community, and relatedness, curiosity to stimulate make-believe fantasy, and learners' intrinsic and extrinsic motivation (Lepper et al., 2005; Lepper & Hodell, 1989).

There are further implications for future co-creation instruction and research. First, as reflected from the VR co-creators' persistent efforts on lower level knowledge co-construction behaviors, it is suggested that the instruction of VR co-creation be invested with even more class time to combat the inefficiency potentially existing in VR co-creation caused by higher technological complexity, as stated by Wang and Sun (2021), to allow abundant and mature higher level knowledge co-construction dialogues to occur. Secondly, appropriate preparatory learning activities, such as the pragmatic training on invitation strategies in virtual worlds, should also be further stressed as scaffolding mediators to elicit higher level knowledge co-construction behaviors and other expected learning outcomes to occur, especially when co-creation is imbued with a considerably high degree of equity and flexibility in leadership and task accountability for higher creativity (Lan, 2016).

There are two limitations to this study. First, due to the random sampling approach, the subgroup gender was not balanced. Specifically, the ratio of males to females in VR co-creation was 73:27, which was higher than that of the other two forms of co-creation, and therefore might to some extent reflect male students' higher motivation to interact with the 3D environment, as well as their strong eagerness for cognitive dissonance resolution and persistent self-looped behaviors to gain familiarity with new technology (Yeh et al., 2018). The second limitation lies in the lack of observation of the visualized interrelationship among the student co-creators. To gain an even deeper understanding of the social interpersonal structure embedded in the knowledge co-construction process of co-creation, it is suggested that social network analysis (SNA) be employed in future research. In terms of networks and graph theory, we may further visualize social relationships among co-creators for the advanced qualitative assessment of interpersonal co-creation activities.

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