Exploring the Impact of Generative Artificial Intelligence Scaffolding on University Students' Collaborative Knowledge Building

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Abstract: Collaborative learning is a significant form of learning in the era of intelligence. Generative artificial intelligence (GAI) holds advantages in providing personalized support for collaborative learning. However, current understanding of how GAI influences university students' collaborative knowledge building is limited. This study aims to address this research gap by empirically examining fthe role of GAI scaffolding in university students' collaborative knowledge building. Fifty-four undergraduates were recruited and divided into 18 groups for the experiment, with 9 groups engaging in collaborative learning supported by GAI scaffolding and the other 9 groups in a conventional technology-supported environment. All participants completed the same collaborative learning task. The results indicate that GAI scaffolding can offer cognitive and metacognitive support, effectively enhancing learners' collaborative knowledge building competences. The primary contribution of this exploratory study lies in providing support for the design and implementation of GAI scaffolding in collaborative learning.

***Keywords*:** generative artificial intelligence; scaffolding; collaborative learning; collaborative knowledge building

1. Introduction

Collaborative learning is a highly effective pedagogical approach that is widely celebrated within the educational community[1]. Existing research has indicated that collaborative learning not only facilitates the sharing of knowledge and emotional interaction among learners but also significantly enhances their cognitive and problem-solving skills[2]. Nonetheless, collaborative learning is subject to various practical challenges. Typically, collaborative learning groups consist of multiple individuals, each with distinct psychological attributes. Upon forming a collective for collaborative learning, these individuals do not spontaneously coalesce into a highly cohesive collaborative entity. Instead, they confront a range of challenges related to cognition, metacognition, motivation, and affect[3]. These challenges may escalate with the complexity of collaborative tasks and the size of the group, leading to issues such as unbalanced participation among learners and superficial interaction. Consequently, the effectiveness, efficiency, and efficacy of collaborative learning may not be adequately assured[4]. Therefore, it is essential to provide scaffolding to students to overcome the difficulties encountered during the collaborative learning process.

Research has indicated a strong correlation between the performance of collaborative learning and the scaffolding provided within it[5]. Extensive discussions have been conducted regarding the provision of strategic and resource-based scaffolding versus intelligent technology scaffolding for students. For instance, Dillenbourg et al. have offered cognitive problem sequences and application strategy scaffolding for learners' problem-solving processes, aiding in the analysis and resolution of issues[6]. Kim et al. have developed a process scaffolding that supports social regulation of learning, encompassing four iterative stages: problem identification, discussion of problem-solving strategies, prioritization of tasks, and role allocation[7]. Molenaar et al. have created a collaborative learning support tool called Ontdeknet, which provides learners with support in activity preparation, planning, and monitoring through virtual agents[8].

Strategic and resource-based scaffolding exhibits a relatively static nature, allowing students to consult relevant materials when encountering difficulties during collaborative endeavors. However, these strategies and resources do not exhibit the characteristic of "strong interaction" with learners. Consequently, the objective of this study is to bridge the gap in the interactivity of scaffolding by proposing a GAI scaffolding supported by intelligent technology and examining its impact on collaborative knowledge building. The structure of the remainder of this paper is as follows. First, a literature review is provided on collaborative learning and the scaffolding practices within it. Following this, a comparative experimental study is presented, where groups utilizing GAI scaffolding are analyzed in contrast to those using other common information technologies for collaborative purposes. Finally, the research findings are synthesized and discussed. In the discussion section, we also address the limitations of the current study and suggest directions for future research.

2. Literature Review

2.1 Collaborative Learning

Collaborative learning is guided by shared learning objectives, where group members engage in interactive communication and collaborative work, jointly undertake learning tasks, and mutually facilitate each other in the process of solving complex problems[9]. Unlike individualized learning approaches, collaborative learning requires group members to build on a foundation of consensus understanding, closely align their learning processes with the collaborative learning objectives, and promptly address various challenges that arise during the learning process [10]. With the advancement of intelligent technology, learners can now engage in comprehensive collaboration both online and offline, breaking free from the spatial and temporal constraints of the past[11]. Through collaborative learning, learners can exchange information with peers and collaboratively construct knowledge and skills. University students who engage in collaborative learning can achieve superior learning outcomes compared to traditional individualized learning methods [12].

However, not all collaborative learning yields favorable learning outcomes. For instance, researchers have found that many instances of collaborative learning remain at a superficial level of information sharing, failing to achieve in-depth negotiation and discussion[13]. Some group members exhibit free-riding behavior, not fully participating in the collaborative learning process[14]. Additionally, researchers have observed that groups often struggle to resolve conflicts, leading to an unsuccessful collaborative learning experience[15]. The design of processual scaffolding in collaborative learning is a key factor influencing the effectiveness of college students' collaborative learning. Therefore, it is necessary to provide scaffolding support for the collaborative learning process. To our knowledge, few studies have investigated how to enhance collaborative learning capabilities through the provision of GAI scaffolding. Hence, this study aims to bridge this gap and examine the use of GAI scaffolding within collaborative learning processes.

2.2 Scaffolding in Collaborative Learning

Scaffolding is conceptualized based on the theory of the Zone of Proximal Development (ZPD) in instructional contexts, which is defined as the distance between actual developmental level and potential developmental level [16]. Scaffolding is conceptualized as the assistance provided by more knowledgeable peers or adults [17]. Existing research indicates that learners can achieve optimal learning outcomes within their ZPD with the support of scaffolding [18]. The scaffolding provided by teachers can offer cognitive and metacognitive support to learners [19]. Cognitive scaffolding guides learners' attention to the knowledge content within collaborative teams by providing text or graphics, engaging learners in cognitive activities and processes related to learning tasks, thereby promoting the acquisition of knowledge [20]. Metacognitive scaffolding offers support in establishing learning goals, planning, role allocation, and process evaluation, prompting learners to enhance their monitoring and attention to the process and outcomes of collaborative learning [21].

In traditional collaborative learning processes, these scaffolds are often provided to learners in a predominantly static manner, which makes it challenging to engage in sustained and meaningful interactions with learners. While teachers can offer dynamic support for learners' collaborative efforts, their ability to do so is constrained by limited attentional resources. When multiple groups simultaneously seek assistance from the teacher, it becomes difficult to provide continuous assessment and personalized guidance to each group. GAI is a technological paradigm that has emerged in recent years, characterized by its high interactivity and the ability to engage with students in a manner similar to an intelligent tutor. This type of AI system can mimic the guiding behaviors of human instructors, offering learners personalized learning experiences and feedback. To our knowledge, there is a scarcity of research investigating the impact of scaffolding based on GAI on collaborative knowledge building.

2.3 Research Questions

This study aims to examine the impact of GAI scaffolding on collaborative knowledge building. The research questions are as follows:

RQ1: What content should be included in the framework of GAI scaffolding?

RQ2: Can GAI scaffolding enhance learners' level of collaborative knowledge building?

3. Methods

3.1 Participants

This study was conducted within the context of higher education. Participants were recruited from a public university in the South China region. A total of 54 undergraduate students voluntarily participated in the study, consisting of 28 males and 26 females, with an average age of 20 years. They were majoring in Digital Media Technology. All participants were divided into 9 experimental groups and 9 control groups. There were no significant differences between the experimental and control groups in terms of gender ($\chi2 = 3.45$, $p = 0.06 > 0.05$), age ($z = 1.26$, $p = 0.08 > 0.05$), and scores in the Digital Media and Film Creation Theory course ($t = 0.08$, $p = 0.81 > 0.05$). Therefore, the two groups were statistically similar in terms of gender, age, and course performance in Digital Media and Film Creation.

3.2 Research Process

The research process is depicted in Figure 1. Before the experiment commenced, all participants took a pre-test to gauge their level of prior knowledge. No significant difference was observed in the prior knowledge level of digital media and film creation between the experimental and control groups ($t = 0.45$, $p > 0.05$). Subsequently, all participants engaged in a collaborative learning activity within the "Shu Ke" (Digital Course) environment. The "Shu Ke" collaborative learning environment was equipped with features such as a menu bar and collaborative dialogue boxes, enabling participants to express their opinions and engage in negotiations regarding the viewpoints raised by their peers. The "Shu Ke" platform also recorded the opinions shared by the students.

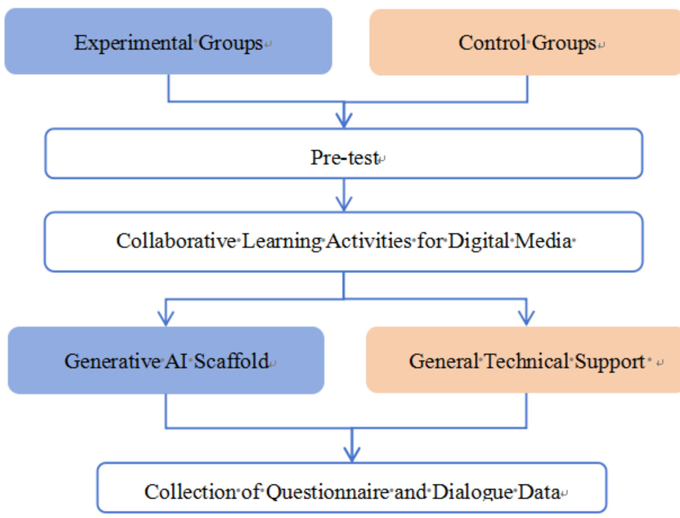

Figure 1. Experimental Design Procedure

The university students participating in this experiment were all from the Digital Media Technology program. Having undergone previous coursework in photography, videography, audiovisual language, and film special effects, the learners had acquired basic skills in film creation. The process of creating digital media film works encompasses multiple stages, from scriptwriting, creating shot lists, to casting, location scouting, and finally shooting, editing, and publishing. During the teaching process, teachers often impose appropriate restrictions on the script direction to facilitate evaluation. Learners develop shot lists based on the determined script content, engaging in in-depth discussions and interactions to form conceptual artifacts of shot lists. This study focuses on observing the quality of interactive dialogue (i.e., collaborative knowledge building) among learners during the process of creating conceptual artifacts of shot lists through collaborative learning.

Collaborative learning scaffolds typically encompass cognitive scaffolds and metacognitive scaffolds. Cognitive scaffolds provide learners with support related to concepts and principles, while metacognitive scaffolds offer assistance with regulatory aspects of learning, such as process monitoring. The GAI tool employed in this study is Zhi Pu Qing Yan, a widely used Chinese-English bilingual large model tool based on ChatGLM in China. This tool utilizes supervised fine-tuning techniques to provide intelligent services in the form of general dialogues. During the research process, the teacher first introduces the basic usage of the tool to the learners, trains them in optimizing interaction prompts, and emphasizes the importance of engaging in dialogue with Zhi Pu Qing Yan at key points in the collaboration or when encountering collaborative obstacles. Based on the general framework of collaborative learning scaffolds, this study designed a GAI scaffold, the structure of which is presented in Table 1.

Table 1. Framework of GAI Scaffold

Type	Subtype	State	Example
Cognitive Scaffolding	Explanation of Concepts	Misconceptions of concepts exist in students' minds.	What is "psychological montage"? Explain with examples.
	Method Explanation	When students seek to deepen their understanding of a concept through a specific case study.	What are the common methods for unskilled connection?
	Metaphor Explanation	Students have misconceptions about concepts.	What are the specific ways to metaphorically slow down time?
Metacognitive Scaffolding	Conceptual Artifact Quality Assessment	Students need to assess the quality of conceptual artifacts during collaborative learning.	Please evaluate the quality of our storyboard: (input the content of the storyboard).
	Conceptual Artifact Normative Check	Students want to check the normativity of expressions related to conceptual artifacts during collaborative learning.	Please check the language and punctuation of our storyboard: (input the content of the storyboard).
	Correction and Improvement of Collaborative Learning Plan	Students want to improve the collaborative learning plan at the initial stage of collaborative learning.	Please improve our collaborative learning plan.
	Improvement Plan for Conceptual Artifacts	Students want to improve the quality of existing conceptual artifacts during collaborative learning.	Please propose an improvement plan for our storyboard: (input the content of the storyboard).

3.3 Instruments

The primary measurement instruments in this study were the pre-test, post-test. The pre-test aimed to evaluate learners' prior knowledge of digital media film and video creation, consisting of 5 multiple-choice questions, 5 fill-in-the-blank questions, and 2 short-answer questions, with a maximum score of 100. The post-test assessed the quality of conceptual artifacts of storyboards, evaluating aspects such as visual element richness, audio-visual language, technical feasibility, and normativity. The differences between the pre-test and post-test were 0.65 and 0.59, respectively, indicating an appropriate difference. The homogeneity reliability of the pre-test and post-test was 0.73 and 0.82, respectively, indicating good reliability. Two experts with extensive experience in digital media film and video creation conducted validity checks and confirmations of the pre-test and post-test. The inter-rater consistency of the pre-test and post-test was 0.81 and 0.83, respectively, indicating good validity.

Building upon the test questions and scales, this study employed a collaborative knowledge building coding framework to encode the dialogue data generated by learners during the collaborative process. Drawing inspiration from the Gunawardena coding framework, this study proposes an analytical framework for collaborative knowledge building focused on creating metaphors. The framework categorizes collaborative knowledge building into five levels:

(1) Idea Sharing (IdS): This level involves learners sharing their perspectives and information.

(2) Idea Arguing (IdA): Learners identify and explore inconsistencies between perspectives at this level.

(3) Idea Negotiating (IdN): Learners engage in discussions to reach a consensus on areas of inconsistency.

(4) Idea Areating (ArC): This level represents the formation of a consensual and innovative understanding of perspectives at the group level.

(5) Irrelevant Discourse (IrD): This category encompasses any content not directly related to the discussion topic.

Two experts with extensive experience in digital media film and video creation coded the learners' collaborative learning process discourse, achieving an inter-rater reliability of 0.9, indicating good reliability.

3.4 Data Analysis Method

This study utilized Epistemic Network Analysis (ENA) to examine the characteristics of collaborative knowledge building. ENA is a quantitative ethnographic technique that models the associative structure of data to represent the internal cognitive networks of learners [22]. The commonly used cognitive framework in ENA is the SKIVE framework, encompassing five dimensions: skills, knowledge, identity, values, and epistemology [23]. This framework represents the associative patterns exhibited by group members in a learning community during collaborative processes, where the connections between cognitive elements are more significant than the elements themselves [24].

ENA involves two fundamental processes: node-based coding and establishment of dynamic network models. Node-based coding includes segmentation and data coding, while dynamic network modeling comprises six processes conducted at the segment level: data accumulation, creation of adjacency matrices, accumulation of adjacency matrices within units, vector normalization, singular value decomposition for dimensionality reduction, and final modeling [25].

4. Results

4.1 Differences in Collaborative Knowledge building Levels

The Mann-Whitney U test was employed initially to analyze the statistical differences in collaborative knowledge building levels between the experimental and control groups. As indicated in Table 2, a significant difference was found in the X-axis dimension at the alpha = 0.05 level (U = 234.00, p = 0.04, r = 0.33), while no significant difference was observed in the Y-axis dimension**.

Table 2. Mann-Whitney Test of Significant Differences

Group	X	Y								
	M	N	U	p	r	M	N	U	p	r
Experimental Group	-0.10	27	234.00	0.04	0.33	-0.15	27	326.00	0.66	0.07
Control Group	0	26				-0.34	26			

Significant at $p<0.05$

4.2 Differences in ENA Network Structure

To better understand the differences in the level of collaborative knowledge building between the experimental and control groups, ENA was used to calculate the average networks for each group's collaborative knowledge building level. Red indicates the cognitive network structure of collaborative knowledge building for the experimental group, as shown in Figure 2, while blue represents the cognitive network structure for the control group, as depicted in Figure 3. The solid squares in the figures represent the average centroid of the group's focus in collaborative knowledge building, and the dashed boxes surrounding the solid squares indicate the 95% confidence interval.

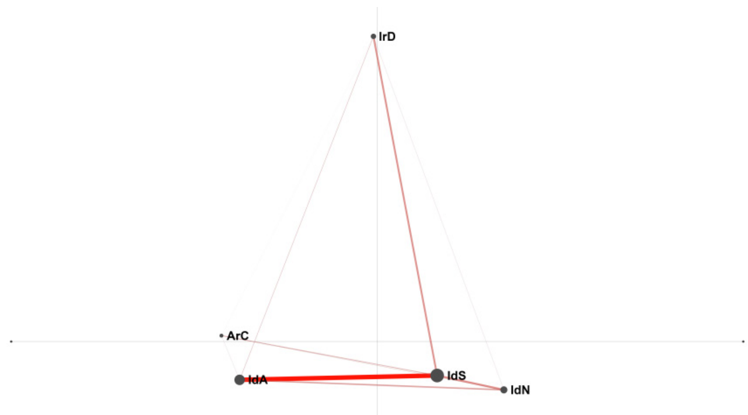

Figure 2. Epistemic Network Structure of Collaborative Knowledge Building for the Experimental Group

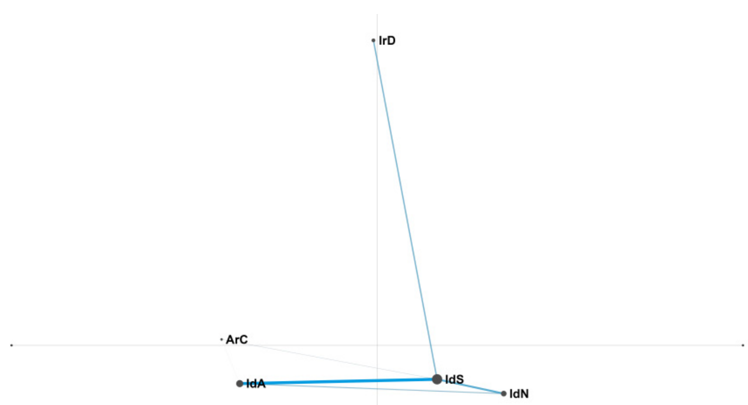

Figure 3. Epistemic Network Structure of Collaborative Knowledge building for the Control Group

The difference in the connectivity coefficients of collaborative knowledge building between the experimental and control groups was determined by subtracting the control group's coefficients from those of the experimental group, resulting in a superimposed difference map, as shown in Figure 4. This figure depicts the two-dimensional structure of the ENA network for collaborative knowledge building, with a cumulative variance proportion of 54.3%. In the ENA, the positive direction of the X-axis defines two types of collaborative knowledge building levels: idea sharing and idea negotiation; the negative direction of the X-axis defines three types: idea argumentation, idea creation, and irrelevant ideas. The positive direction of the Y-axis defines two types: creation and irrelevant ideas; and the negative direction of the Y-axis defines three types: idea sharing, idea argumentation, and idea negotiation.

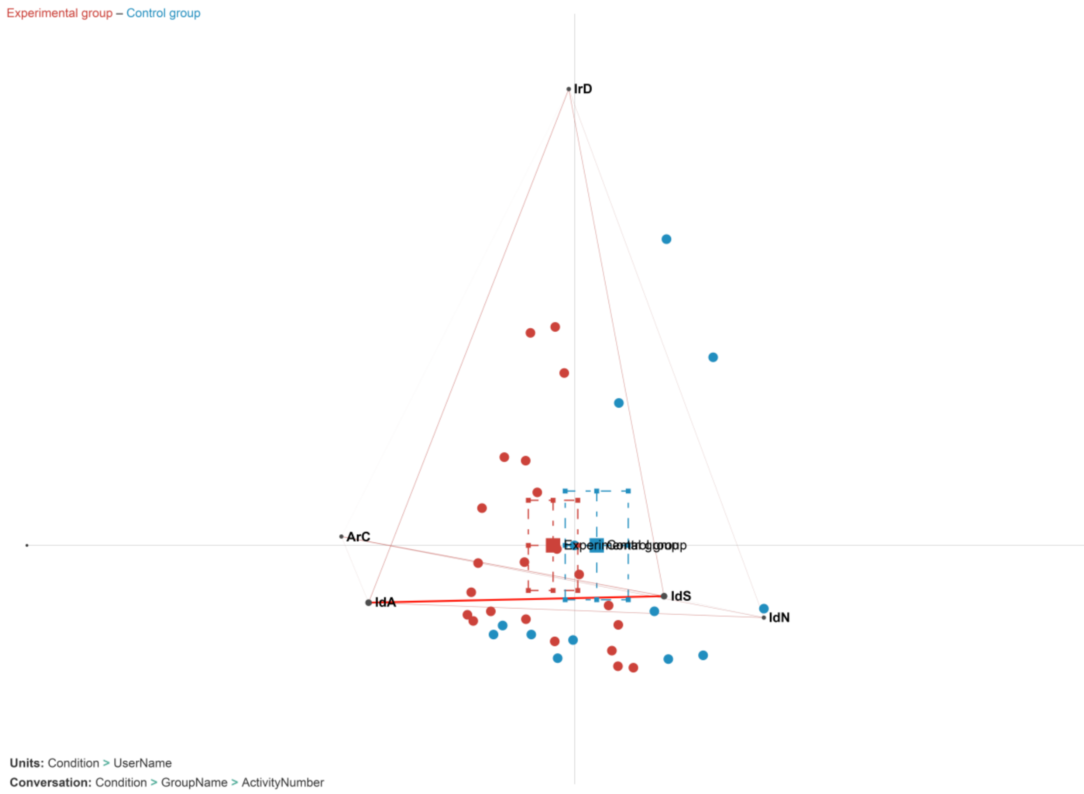

Figure 4. Mean epistemic reduction network between the experimental and control group

In the figure, red lines denote connections where the experimental group exhibits a higher level of collaborative knowledge building than the control group, while blue lines indicate connections where the control group surpasses the experimental group. The thickness of the lines represents the magnitude of the difference coefficient. Table 3 presents the difference coefficients for the connections between various levels of collaborative knowledge building. During the experimental activities, a total of eight connections with significant differences in the level of collaborative knowledge building were identified, with the experimental group outperforming the control group in each instance. Of these, four connections have difference coefficients greater than 0.5, specifically: idea sharing - irrelevant ideas, idea sharing - idea creation, idea argumentation - idea negotiation, and idea negotiation - idea creation.

Table 3. Difference Coefficients in Collaborative Knowledge building Levels Between the Experimental and Control Groups

Serial Number	Type of Collaborative Knowledge building	Experimental Group - Control Group
1	IdS-IdA	0.20
2	IdS-IrD	0.06
3	IdS-ArC	0.07
4	IdN-ArC	0.05
5	IdS-IdN	0.01
6	IdA-ArC	0.02
7	IdN-IrD	0.03
8	IdA-IdN	0.06

5. Discussion

In terms of the characteristics of group collaborative knowledge building, the experimental group, supported by GAI scaffolding, exhibited more collaborative knowledge building behaviors such as idea sharing - idea creation, idea negotiating - idea creating, and idea arguing - idea negotiation. The significant difference in the co-occurrence of idea sharing - idea creating may be related to the collaborative practical activities in this study. The collaborative learning activities involved in this research are associated with digital media film and television production. During the initial discussion phase, group members based their discussions on their existing experience in film and television creation. For instance, in the discussion of challenges encountered and coping strategies in the film and television production process, group members actively shared their perspectives. However, their peers did not engage in "legitimacy" argumentation on these views but instead proposed new perspectives. This led to a consensus being reached without in-depth discussion, despite a substantial amount of shared viewpoints. Existing research indicates that the convergence of viewpoints in collaborative knowledge building primarily includes three stages: proposing viewpoints, connecting viewpoints, and intelligent convergence [26]. However, at the intelligent convergence stage, different types of convergence can be achieved based on the varying degrees of viewpoint processing. If a group reaches convergence without fully exploring the similarities and differences between viewpoints, a "pseudo-convergence" state is formed, which is a low-level convergence form that fails to achieve shared understanding [27].

From idea arguing to idea negotiating and ultimately to idea creating , the study reflects the continuous improvement in the level of collaborative knowledge building. This finding corroborates existing research. The study revealed a significant difference between idea sharing and irrelevant ideas. Although irrelevant ideas were not directly related to the knowledge building activities the groups were engaged in, they originated from the daily learning and life experiences of the group members and were topics they were eager to share and discuss. While most studies place irrelevant ideas outside the coding system, this research found that, excluding extremely irrelevant topics, many discussions that seemed "unrelated" to the current topic could moderate the collaborative atmosphere to some extent and contribute to the ongoing progress of collaborative learning. Previous research has found that interactions unrelated to the collaborative task can facilitate collaborative knowledge building [28]. Lin et al. discovered a significant correlation between irrelevant ideas and academic knowledge discussions [29]. Interviews with members of the experimental group also illustrate the positive role of irrelevant ideas. Some interviewees indicated that irrelevant ideas played a particularly significant role in the early stages of collaboration, as they could strengthen communication between members, further enhance group cohesion, and provide foundational support for the subsequent advancement of collaborative tasks.

Comparing the collaborative knowledge building behaviors between the experimental group and the control group, the notable differences are as follows: compared to the control group, the experimental group exhibited a higher frequency of knowledge building behaviors across all five coding levels, indicating that the intervention of GAI scaffolding is beneficial in enhancing the activity level of group collaborative knowledge building. The study also revealed the distinctiveness in the collaborative knowledge building behaviors between the experimental and control groups. Firstly, the experimental group demonstrated more idea negotiating - idea creating and idea creating - idea creating behaviors than the control group, reflecting the experimental group's commitment to driving the continuous improvement of ideas and advancing towards higher-order development. This suggests that GAI scaffolding plays a significant role in facilitating the refinement of ideas. Secondly, while the control group exhibited idea arguing - idea negotiating behaviors, they did not engage in creative-level behaviors. This situation may be attributed to the absence of GAI scaffolding.

However, this study is subject to certain limitations. Firstly, the collection of processual data in this study remains relatively simplistic, and objective data from the learners' embodied level has not been obtained, which may leave the research conclusions in need of further persuasive power. Secondly, during the creation of digital media film shot scripts, learners tend to veer off into areas such as acting performance, making it difficult to achieve continuous improvement of the discussed viewpoints. Although group members actively proposed different viewpoints, subsequent peers often lacked the continuity and response to preceding viewpoints, or the responses were lacking in dialecticism. This resulted in a discrete distribution of viewpoints and a brief lifecycle of ideas. Although each group ultimately reached a consensual understanding, the conceptual artifacts of shot scripts constructed through this approach are at a lower level of creativity, falling short of the ideal higher-order state.

6. Conclusion

This study aimed to examine the impact of GAI scaffolding on collaborative knowledge building. The findings reveal that GAI scaffolding encompasses cognitive and metacognitive scaffolds. Such scaffolding facilitates learners in achieving deep collaborative knowledge building, and learners express high satisfaction with the GAI scaffolding. This study provides valuable insights for interventions in collaborative learning.

Future research could employ multimodal analysis methods to form a more comprehensive approach to data collection in collaborative processes, capturing learners' discourse, physiological, and bodily cues. Strengthening the role of teachers in the collaborative learning process by deeply integrating human intelligence with machine intelligence could maximize the precision of teaching interventions. Additionally, guided by relevant teaching and learning theories, the design of collaborative learning activities could be optimized to better reflect the creative metaphor in learning, thereby serving the cultivation of learners' innovative thinking.

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