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Lanqin Zheng

Data-Driven Design for Computer-Supported Collaborative Learning

Design Matters

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Series Editor's Foreword

Computer-supported collaborative learning has been widely used in elementary, secondary, and higher education. The major concern of CSCL centers on how people learn together through computers. CSCL contributes to human growth and development through co-constructing knowledge, skills, emotions, attitudes, and values. However, previous studies mainly focus on developing CSCL environments or validating the effectiveness of particular interventions. Very few studies center on how to design and optimize CSCL activities. Moreover, front-line educators often find it is challenging to design CSCL in practice. This monograph is structured into 11 chapters and it highlights the importance of design in CSCL by proposing data-driven design and assessment methods.

I am honored to have such a timely and comprehensive monograph written by Dr. Lanqin Zheng. Dr. Lanqin Zheng made great efforts in proposing innovative frameworks about CSCL activities, task design, scaffolding design, and learning analytics for design. In addition, four case studies on promoting learning interests, programming skills, knowledge building, and cross-cultural collaborative learning were illustrated in-depth to provide insights into how to implement CSCL in practice. Finally, Dr. Lanqin Zheng proposed how to evaluate CSCL design quality and the fidelity of enactment in CSCL. In addition, how to optimize CSCL activities based on a data-driven approach was also proposed by Dr. Lanqin Zheng.

I believe that the topics of this monograph are very valuable not only for researchers but also for teachers. The original methodological contributions to designing CSCL activities and assessment design quality as well as the fidelity of enactment making this an essential read for anyone interested in collaborative learning. This monograph will also be of interest to a wide audience of educators, practitioners, and students in the field of CSCL as well as the fast-growing community of people who are interested in how to optimize design and learning performance by CSCL. Hopefully, the readers can benefit a lot from this monograph.

Beijing, China — Prof. Ronghuai Huang

Preface

Design is one of the important attributes of teaching and learning. However, design is often neglected in practice. This monograph highlights how to design CSCL activities and evaluate CSCL design quality. The first part aims to propose how to design collaborative learning activities based on a data-driven design approach. The data-driven design focuses on the processing of data and improving design quality based on the analysis results. The second part aims to share interesting cases of computer-supported collaborative learning activities. The last part demonstrates how to evaluate design quality and the fidelity of enactment based on design-centered research. The design-centered research aims to develop the knowledge about how to design and analyze the deficiency of design.

This monograph contains several illustrations of innovative, including CSCL design frameworks, using learning analytics to optimize CSCL design, interesting and innovative CSCL activities in authentic learning environment, design-centered research approach to evaluating design quality as well as the fidelity of enactment in CSCL, and data-driven approach to optimizing collaborative learning activities. This monograph is structured into three parts.

Part I

The first part of this book consists of four chapters. This part focuses on how to design CSCL activities. Chapter 1 proposes a novel framework for designing computer-supported collaborative learning activities. Chapter 2 proposes a holistic framework of task design for CSCL. Chapter 3 develops a collaborative learning analysis framework to illuminate how to analyze collaborative learning in-depth. Chapter 4 designs and optimizes scaffolding based on the data-driven approach in CSCL context.

Part II

The second part of this book consists of four chapters. This part aims to share interesting case studies on CSCL. Chapter 5 shares how to foster learning interest in STEM (Science, Mathematics, Engineering, and Technology) based on the interest-driven creation theory. Chapter 6 proposes how to improve pupils' programming skills through an innovative collaborative programming model. Chapter 7 focuses on how group members co-constructed knowledge and completed group products with the aid of scripts in a cross-cultural collaborative learning context. Chapter 8 shares teacher scaffolding-supported collaborative knowledge building in online learning environment.

Part III

The third part of this book consists of three chapters. This part aims to evaluate design quality and the fidelity of enactment based on design-centered research. In chapter 9, the author proposes an innovative method of evaluating the design quality of CSCL activity. Chapter 10 proposes how to analyze the fidelity of enactment in CSCL through qualitative and quantitative analysis methods. Chapter 11 proposes how to optimize collaborative learning activities and evaluate the effectiveness of optimization strategies.

Acknowledgments

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I would like to express my gratitude to all those who provided support and help for me. Very special thanks to Prof. Ronghuai Huang who directed me to the field of computer-supported collaborative learning. I truly appreciate Prof. Kaicheng Yang who guided me to focus on designing based on design-centered research. I would like to express my gratitude to Sophie Li and Miao Zhang who facilitated the publication of this book. Sincere thanks to my students, including Xuan Zhang, Lu Zhong, Jiayu Niu, Renxue Liu, Xingxing Huang, and Juliana who helped me to collect and analyze data. I am grateful for the support from my family my father, my husband, and my lovely son. My loving thanks to you!

I am very proud to present my second monograph written in English by myself. I am convinced that my efforts will contribute to grasp the value of computer-supported collaborative learning and improve the quality of learning for our kids and us.

Thank you very much.

Beijing, China Lanqin Zheng

Contents

Part I
Data-Driven Design for Computer-Supported Collaborative Learning

Chapter 1
An Innovative Framework for Designing Computer-Supported Collaborative Learning

Abstract The past three decades have seen tremendous growth in the application of computer-supported collaborative learning in the field of education. However, front-line educators often find it challenging to design CSCL in practice. This chapter will propose a novel framework for designing computer-supported collaborative learning activities to improve the quality of CSCL. This framework is composed of eight design elements, including learning goals, tasks, interactions, resources, assessment, implementation, analysis, and optimization. These elements contribute to making design decisions for teachers and practitioners. A case illustrates how to adopt this framework to design, implement, and optimize CSCL activity. This framework can help teachers avoid subjective bias and improve collaborative learning quality further.

Keywords Collaborative learning · Design framework · Learning activity

1.1 Introduction

Collaborative learning is the situation where participants engage in learning together or solve problems collectively (Dillenbourg, 1999; Roschelle & Teasley, 1995). Collaborative learning contributes to the development of domain knowledge, long-term retention of concepts, and sharing understanding (Garrison et al., 2001; Johnson & Johnson, 1999). Computer-supported collaborative learning (CSCL) is regarded as a new branch of learning science, which focuses on how individuals learn together with the assistance of computers (Stahl et al., 2014). The values of CSCL have been found by many researchers, such as improvement of academic performance (Zheng et al., 2019), cultivation of critical thinking (Daradoumis et al., 2013), and the promotion of self-efficacy (Narayan, 2014).

In the field of CSCL, most studies focus on learning environment (Baker & Lund, 1997), the design of technological products (Stahl et al., 2006), interaction analysis (Sing & Khine, 2006), knowledge building (Scardamalia & Bereiter, 2014), group cognition (Stahl, 2012), and scripted roles (Fischer et al., 2013). Stahl (2012) indicated that technology was undeniably essential to CSCL and technological advances could promote CSCL innovations continuously. Therefore, many

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researchers focus on how to utilize advanced technologies to support collaborative learning. For example, Anaya et al. (2016) developed an intelligent tool to analyze interactions and demonstrate collaboration circumstances through a decision tree. Alberola et al. (2016) developed an artificial intelligence tool to format heterogeneous team in the classroom to improve team dynamics and satisfaction. However, the applications of technologies are not enough to improve collaborative learning quality.

CSCL activities need to be designed elaborately to orchestrate different factors, such as tasks, interactive strategies, learning resources, assessment, and so on. However, very few studies investigate how to conduct collaborative learning design. Although Pozzi and Persico (2013) proposed a 4T model (task, time, team, technology) for CSCL design, it still lacked assessment and optimization based on analysis results. De Hei et al. (2016) developed a group learning framework, including learning objectives and outcomes, task characteristics, interaction, structuring, guidance, group constellation, assessment, and facilities. However, these components are overlapped to a large extent. To close this research gap, this study focused on how to design collaborative learning activity to engage learners in productive and successful collaborative learning.

1.2 Literature Review

Collaborative learning includes five essential elements, namely positive interdependence, individual accountability, productive interactions, social skills, and group processing (Johnson & Johnson, 1999). To achieve productive and successful collaborative learning, it is recommended to design collaborative learning activities carefully in advance (Dillenbourg et al., 2009). Furthermore, providing learners with information and communication technology does not automatically result in the occurrence of collaborative learning (Strijbos et al., 2004). Therefore, the learning goals, tasks, collaborative learning environment, interactive strategies, and assessment methods should be considered and designed elaborately. The design of CSCL requires the orchestration of different elements to promote the attainment of learning goals.

In CSCL field, most studies focused on local elements of collaborative learning to design and implement collaborative learning activities. For example, Wang and Lin (2007) examined different group composition on discussion behaviors and group performance. Wang et al. (2017) examined the knowledge construction and cognitive patterns using four interactive strategies (problem solving, peer assessment, peer tutoring, and role playing). They found that learners demonstrated more cognitive process of "understanding" using peer assessment and peer tutoring as well as more cognitive process of "creation" using role playing and problem solving. Hernández-Sellés et al. (2019) conducted a survey about the relationships among online interactions, emotional support, and collaboration tools. They found that online collaborative tools contributed to interactions among group members and emotional support. In addition, many researchers developed online collaborative learning environment or advanced systems to support CSCL. For example, Adefila et al. (2020) developed a virtual patient simulation in a computer-supported collaborative learning environment to promote learning engagement and learning experiences and found that virtual patient simulation tools promoted skill acquisitions. Liaw et al. (2019) designed and developed a 3D virtual environment to support collaborative learning for interprofessional team care delivery. They found that students demonstrated significant improvements in their attitudes toward healthcare teams and experiences of interprofessional collaboration. Bause et al. (2018) employed a shared space to support collaborative learning and foster problem solving and they found that groups with shared space achieved greater discussion intensity, more mutual understanding, and better decision performance.

In terms of design approaches, there are two approaches to designing CSCL activities. One is design-based research (DBR), another is design-centered research (DCR). Most studies adopted DBR to design a collaborative learning environment or a particular intervention in CSCL. For example, Lyons et al. (2020) adopted design-based research to develop a web-based tool to promote social regulations in collaborative learning. Wang (2020) employed design-based research to examine the effects of technology-enhanced learning mode on active learning. However, very few studies adopted a design-centered research approach to design CSCL activities. To the best of our knowledge, only Zheng et al. (2020) adopted the design-centered research approach to design and implement collaborative learning activities and examine the alignment between design and enactment. They found that the alignment significantly improved after the optimization of collaborative learning design. They also found that the alignment was positively related to the improvements in group performance.

1.3 A Framework for Designing CSCL Activities

This study proposed an innovative CSCL designing framework with eight elements, including goals, tasks, interactions, resources, assessment, implementation, analysis, and optimization. The purpose of including implementation, analysis, and optimization was to emphasize that design of CSCL was iterative and need to be refined continuously. More specifically, CSCL design includes eight steps, namely setting collaborative learning goals, designing collaborative learning tasks, designing interactive strategies, developing collaborative learning resources, designing assessment methods, implementation of collaborative learning activities, analyzing collaborative learning processes and outcomes as well as optimization of collaborative learning design. Figure 1.1 shows the framework for designing collaborative learning activities. The following sections will illustrate the eight elements step by step.

Step 1: Set collaborative learning goals and objectives

Setting collaborative learning goals and objectives is the first step for designing collaborative learning activities, which is very crucial for productive and successful collaborative learning. Learning goals and objectives specify the breadth and depth of

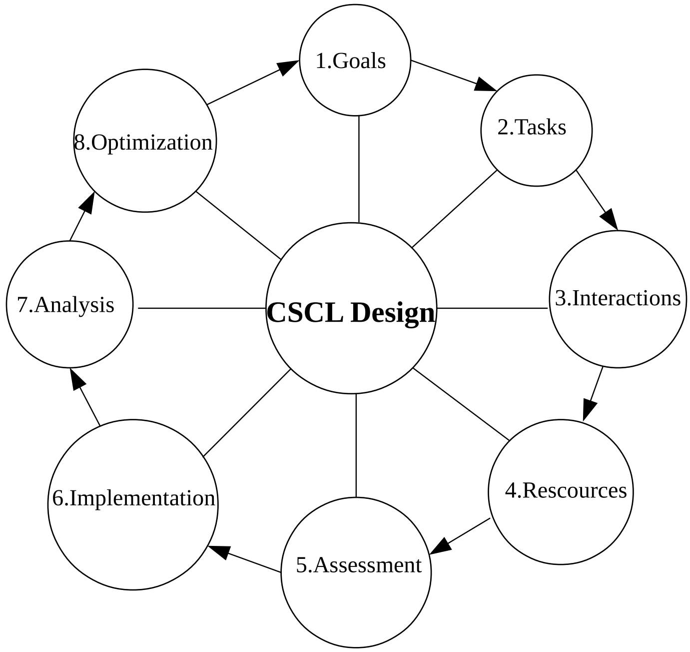

Fig. 1.1 The design framework of CSCL

content to align learning with the curriculum standards (Trafton & Midgett, 2001). Learning goals and objectives provide an important reference point for designing other elements. When designing collaborative learning goals and objectives, teachers and practitioners should specify the domain knowledge, skills, emotions, attitudes, and values. The domain knowledge includes the target knowledge and their relationships and it can be represented in a target knowledge map. Skills including problem-solving skills, communication and collaboration skills, and so on. Emotions, attitudes, and values should be indicated when design CSCL goals and objectives. For example, collaborative learning should foster positive emotions, attitudes, and values.

Step 2: Design collaborative learning tasks

Collaborative learning tasks should be designed according to collaborative learning goals and objectives. Generally speaking, there are two types of tasks, one is meaning-making and another is problem solving. When designing collaborative learning tasks, designers should carefully consider six aspects, namely task interdependence, difficulty, complexity, sequences, outcomes, and assessment methods.

Task interdependence was defined as the interconnections between tasks that one specific part of work depends on the completion of another part of work (Van der Vegt et al., 1998). Task interdependence reflects the degree to which group members depend on each other for learning performance (Kirschner et al., 2011). Task interdependence serves as the glue that bring group members together (Van Gennip et al., 2010). It was found that increased task interdependence leads to increased learning outcomes (Nebel et al., 2017). In addition, tasks difficulty and complexity levels should be tailored to learners' skill levels. Task sequences should be arranged from simple to difficult. Different sub-tasks should be interdependent to achieve better learning performance. The outcomes of tasks include group products and task requirements, which should be clearly indicated when designing collaborative learning tasks. The assessment methods should indicate how to evaluate the processes and outcomes of tasks.

Step 3: Design interactive approaches

It has been widely acknowledged that social interaction is a crucial element in collaborative learning (Guanawardena et al., 1997; Kreijns et al., 2003). As Kreijns et al. (2003) revealed that "If there is no social interaction then there is also no real collaboration." To achieve productive social interactions, the designer should carefully design interactive approaches before collaborative learning. The interactive approaches include interactive strategies and interactive rules. The typical interactive strategies include discussion, brainstorm, jigsaw, argumentation, role assignment, peer assessment, peer tutoring, and so on. These interactive strategies can be employed and selected based on collaborative learning goals and tasks. Furthermore, the procedure of each interactive strategy should be clearly provided for learners. If learners are not familiar with the interactive strategy, the particular training should be conducted before collaborative learning. In addition, interactive rules include how to interact with each other, how to negotiate and solve conflicts, how to avoid free riding, and so on. It has to be noted that the discourse and discussions among peers cannot be designed in advance since collaborative learning interaction is an emerging process (Kapur et al., 2011).

Step 4: Develop collaborative learning resources

Collaborative learning resources were very important for successful collaborative learning. Collaborative learning resources include a collaborative learning environment, various kinds of learning materials, and so on. Kreijns et al. (2003) believed that collaborative learning mainly aimed at providing a collaborative learning environment to enhance learning. A collaborative learning environment provided a shared space to facilitate information sharing and collaboration (Chávez & Romero, 2014). Therefore, it is recommended to develop a collaborative learning environment to engage learners in productive interactions and collaboration. More specifically, the CSCL environment should support online discussion, collaborative drawing or writing, sharing resources, and visualization of collaborative learning processes and outcomes.

Step 5: Design assessment methods

Collaborative learning assessment methods include formative assessment and summative assessment. In addition, designers should specify the assessment criteria in detail to stimulate learners' motivations. The assessment criteria indicated how to assess peers' works and collaborative learning processes. When designing the assessment criteria, designers should consider content, format (qualitative or quantitative or both), scores, and feedback methods (written, oral, video, or mixed feedback).

Furthermore, the assessment criteria should be provided for learners in advance to prepare group products better.

Step 6: Implement collaborative learning activities

After completing the aforementioned five steps, collaborative learning activities can be conducted in different modes, including face-to-face, mobile CSCL, blended CSCL, and online collaborative learning mode. In terms of contexts, CSCL activities can be implemented in a lab, classrooms, outdoor, and anywhere. However, the whole collaborative learning processes should be recorded through cameras or online collaborative learning systems. During collaborative learning process, teachers should provide scaffold and help whenever learners need. Teachers should be a mentor or facilitator rather than a sage on the stage to promote productive collaborative learning.

Step 7: Analyze collaborative learning processes and outcomes

After the implementation of collaborative learning activities, the processes and outcomes of collaborative learning as well as the alignment between CSCL design and enactment should be analyzed in depth. The purpose of the analysis is to identify the problems of designing and enactment to optimize collaborative learning. The processes and outcomes of collaborative learning can be analyzed from different perspectives. Learners' engagement, knowledge building levels, interactive relationships, behavioural patterns, emotional status, metacognition, motivations, and group products were analyzed in different ways. For example, the content analysis method can be adopted to analyze learning engagement, knowledge building level, metacognition, and emotional status. The social network analysis method can be used to analyze interactive relationships and patterns. Lag sequential analysis method can be adopted to analyze behavioural patterns. In addition, the alignment between CSCL design and enactment can be analyzed using design-centered approach. The three indicators including the range of activated knowledge, the degree of knowledge building, and interactivity of the approach proposed by Zheng et al. (2020) can also be adapted to analyze the alignment.

Step 8: Optimize collaborative learning design

Optimization of collaborative learning design aims to improve the design quality, learning performance, and promote teachers' professional development. The collaborative learning goals, tasks, interactive strategies, learning resources, and assessment methods could be optimized further based on the analysis results. After optimization, the second round of collaborative learning can be implemented to examine the effectiveness of optimization strategies.

1.4 The Case Study

1.4.1 The Collaborative Learning Design Plan of the First Round

To validate the proposed CSCL design framework, a collaborative learning case about conceptual change was conducted using the proposed framework. The following will illustrate the example in terms of the design plan, analysis results, and optimized design plan. Table 1.1 shows the collaborative learning design plan of the first round.

Table 1.1 The collaborative learning design plan of the first round

Elements	Content
Goals	The collaborative learning goal was to understand the conceptions, examples, and principles of conceptual change as well as how to promote conceptual change.
Tasks	Teacher Zhang found that students had difficulties in understanding of the conception about force during throwing a ball. It was found that there were some differences in explanations about the force of throwing a ball between the students and experts. The students believed there were two kinds of forces during throwing a ball, including gravity and a kind of force that overcame gravity. However, the experts believed that there was only one kind of force during throwing a ball and it is gravity. Therefore, please help the teacher Zhang to change students' misconceptions. Your group can discuss from the following aspects: • What is conceptual change? Please give some examples about conceptual change. • What are the principles of conceptual change? • Sometimes, it is very difficult for learners to change previous misconceptions. Why? • Do you think different subject domains have impacts on conceptual change? • How to promote conceptual change? Please work out at least three strategies and give examples
Interactions	Group members conducted online discussion through the social media tool and co-writing tool to complete the task.
Resources	Learning materials about conceptual change, including literatures, textbooks, and online learning resources.
Assessment	The group product included the ideas and plans about conceptual change. It was evaluated in terms of the correctness of ideas, diversity of ideas, the appropriateness of examples, and precision of solutions.
Implementation	All of the group members conducted online collaborative learning for three hours.
Analysis	The researchers analyzed online discussion transcripts and group products in depth.
Optimization	The collaborative learning design plan was optimized based on the analysis results.

1.4.2 The Analysis Results of the First Round

Then CSCL activity was carried out for three hours. And then, the processes and outcomes of collaborative learning were analyzed in terms of learning engagement, individual contribution, knowledge elaboration, knowledge convergence, emotions, metacognition, interactive path, group product, and the alignment between design and enactment. The following will illustrate the analysis result one by one.

Students' learning engagement was calculated through the number of information flows during online collaborative learning. It was found that the group leader output 180 information flows, the monitor output 164 information flows, and the information searcher output 219 information flows. Therefore, the information searcher engaged more than other members in online collaborative learning.

Individual contribution was measured through the activation quantity, which can be automatically calculated via our analytic tool. The results indicated that the activation quantity of group leader reached 189.21. The activation quantity of the monitor and information searcher achieved 206.53 and 177.6, respectively. Thus, the monitor had more contributions than the group leader and information searcher.

Knowledge elaboration and knowledge convergence can be automatically calculated via our analytic tool. The details about how to calculate knowledge elaboration and knowledge convergence can be referred to a previous study published by Zheng (2017). The findings revealed that knowledge elaboration reached 1243.746 and knowledge convergence reached 632.5.

The emotions of group members were classified into positive, negative, and neutral according to Pang and Lee (2008). It was found that all of the group members demonstrated positive emotions and the proportion achieved 0.979. The negative and neutral emotions reached 0.014 and 0.007, respectively.

Furthermore, the metacognitive behaviors were analyzed and the findings revealed that setting goals and making plans achieved 50.6%, monitoring learning process reached 35.2%, and reflecting and evaluating only reached 6.2%. Therefore, the reflecting and evaluating should be enhanced further in the next round of collaborative learning.

In addition, the group product was evaluated in terms of correctness of ideas, diversity of ideas, the appropriateness of examples, and precision of solutions. The scores of the above-mentioned dimensions achieved are 23, 22, 20, and 22. The final score was 87. The examples of conceptual change should be revised further in the next round of collaborative learning.

The interactive path of collaborative learning is shown in Fig. 1.2. It was found that the interactive paths of the group members were in line with the expected paths. Therefore, the group completed the expected collaborative learning tasks.

The alignment between design and enactment was also analyzed in depth. The findings revealed that the alignment of knowledge building level achieved 0.653. Therefore, the knowledge building level needs to be improved further in the next round of collaborative learning. Figure 1.3 shows the target knowledge map and Fig. 1.4 demonstrates the knowledge map generated by the group.

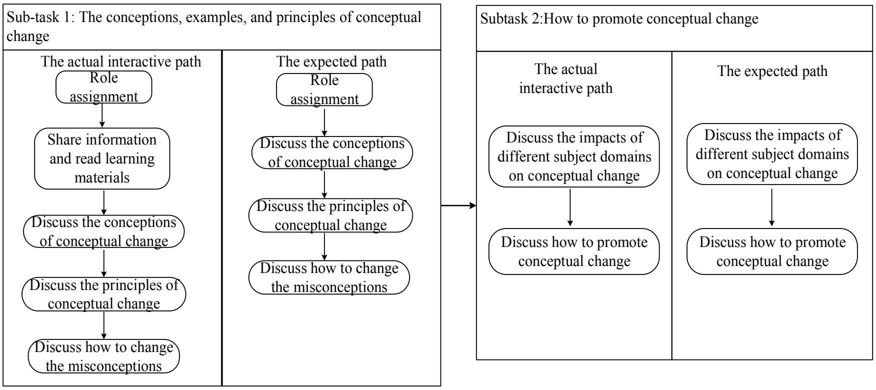

Fig. 1.2 The interactive paths

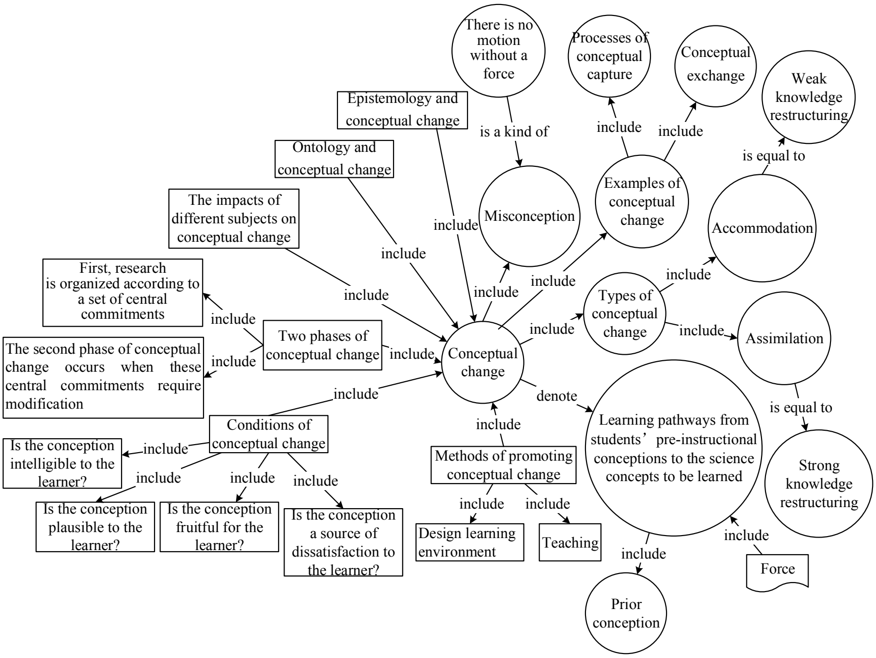

Fig. 1.3 The partial target knowledge map

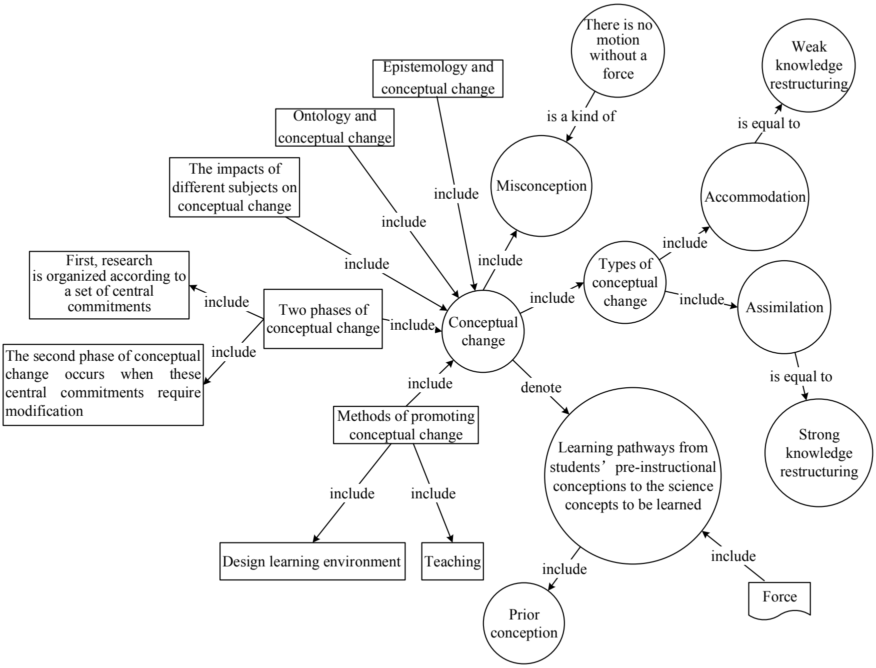

Fig. 1.4 The partial knowledge map generated by the group

1.4.3 The Collaborative Learning Design Plan of the Second Round

To improve online collaborative learning quality and learning performance, the collaborative learning design plan of the first round was revised and optimized based on the aforementioned analysis result. Table 1.2 shows the collaborative learning design plan of the second round.

1.5 Discussion and Conclusions

This study proposed a CSCL design framework and conducted a case study to validate the feasibility of this framework. The results indicated that the proposed framework was very effective and reasonable for guiding CSCL design and implementation. Careful consideration and design of eight elements can help teachers and practitioners avoid assumptions and subjective judgment about collaborative learning. As Van den Berg et al. (2006) indicated that optimizing the design elements contributes to improving learning outcomes and satisfaction. The proposed CSCL design framework also indicated that design is an iterative process and can be refined continuously.

Table 1.2 The collaborative learning design plan of the second round

Elements	Content
Goals	The collaborative learning goal was to understand the conceptions, examples, and principles of conceptual change as well as how to promote conceptual change.
Tasks	Teacher Zhang found that students had difficulties in understanding of the conception about force during throwing a ball. There were some differences in explanations about the force during throwing a ball between the students and experts. The students believed there were two kinds of forces during throwing a ball, including gravity and a kind of force that overcome gravity. However, the experts believed that there was only one kind of force during throwing a ball and it is gravity. Therefore, please help the teacher Zhang to change students' misconceptions. Your group can discuss from the following aspects: • What is conceptual change? Please give some examples about conceptual change. • What are the principles of conceptual change? • Sometimes, it is very difficult for learners to change previous misconceptions. Why? • Do you think different subjects have impacts on conceptual change? • How to promote conceptual change? Please work out at least three strategies and give examples.
Interactions	Group members conducted online discussions through the social media tool and co-writing tool to complete the task. The scripts about collaborative learning sequences were provided for group members. The recommended role assignment includes the group leader, the monitor, and the information searcher. The group leader is responsible for organizing, managing, negotiating, and summarizing. The monitor is responsible for monitoring and controlling learning progress, questioning, reflecting, and evaluating. The information searcher is responsible for searching information and providing explanations. In addition, the interactive strategies include brainstorming, discussion, and argumentation. The tips about interactive strategies were also provided for group members.
Resources	Learning resources include learning materials about conceptual change, including textbooks, literature, tools, and online learning materials. In addition, the cognitive and metacognitive scaffolding was also provided for group members to promote collaborative knowledge building.
Assessment	The group product included the ideas and plans about conceptual change. It was evaluated in terms of the correctness of ideas, diversity of ideas, the appropriateness of examples, and precision of solutions.
Implementation	All of the group members conducted second round of online collaborative learning for three hours. Teachers provided help when necessary.
Analysis	The researchers analyzed online discussion transcripts and group products in depth.
Optimization	The collaborative learning design plan was optimized further based on the analysis results.

This study highlighted the importance of design and provided insights into how to design CSCL activities.

The present study had several implications for teachers, researchers, and practitioners. First, CSCL design is very crucial for improving collaborative learning quality and performance. The proposed eight elements were indispensable for high-quality collaborative learning. However, many studies only focus on parts of elements (Chen & Kuo, 2019; Shin et al., 2020; Yilmaz & Yilmaz, 2020), which resulted in poor collaborative learning performance. It is suggested that the proposed CSCL framework should be considered and adopted when designing collaborative learning activities.

Second, design-centered approach (DCR) is very significant for improving teachers' professional development. The DCR approach puts emphasis on the alignment between design and enactment as well as the deficiency of design (Zheng et al., 2020). This approach contributes to developing technological knowledge about collaborative learning design through analysis of deficiency. Therefore, it is recommended to adopt design-centered approach to design CSCL activity.

Third, data-driven design and analysis was very useful and effective for improving collaborative learning design quality. The analysis results serve as a bridge to link CSCL design and implementation. The data-driven design contributes to avoiding personal subjective experiences and bias. Therefore, it is suggested that the data-driven design approach should be considered and adopted during the design of collaborative learning activities.

However, this study had several limitations and caution should be observed when generalizing the results. First, only one case study was carried out in the present study. Future studies will expand the same size and conduct the empirical study to validate and refine the proposed framework. Second, the duration of collaborative learning was short in this study. Future studies will conduct longitudinal studies to validate and optimize the proposed framework further.

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Chapter 2
The Model of Task Design in Computer-Supported Collaborative Learning

Abstract Computer-supported collaborative learning (CSCL) has been widely adopted in higher education and K-12. To achieve successful collaborative learning, task design is regarded as the major concern. However, very few studies focus on how to design collaborative learning. To close this gap, this chapter proposed a holistic model of task design for CSCL. This model includes six elements, namely task goals, contexts, problems, sequences, resources, and assessment. Furthermore, two cases about artificial intelligence illustrated how to use the proposed model to design CSCL tasks. The implications and future studies were also discussed in depth.

Keywords Collaborative learning · Task design · Task characteristics

2.1 Introduction

Computer-supported collaborative learning (CSCL) has been widely adopted in K12 and higher education. CSCL contributed to improving learning performance (Shin et al., 2020; Wang et al., 2020), problem-solving skills (Andrews-Todd & Forsyth, 2020), and social skills (Notari et al., 2014). However, not all collaborative learning can improve collaborative learning outcomes. There are many factors that affect the effectiveness and efficiency of CSCL, including prior knowledge, collaborative learning environment, group experiences, teacher guidance, and task characteristics. For example, Zambrano et al. (2019a) investigated the effects of task-specific prior knowledge on collaborative learning and they revealed that knowledgeable collaborative groups outperformed novice collaborative groups in collaborative learning outcomes. Sangin et al. (2011) developed a knowledge awareness tool to visualize peers' prior knowledge during collaborative learning and they found that the knowledge awareness tool significantly improved collaborative learning outcomes. Zambrano et al. (2019b) examined the effects of group experiences on collaborative learning outcomes and they found that experienced groups were more efficient than inexperienced groups when tasks required processing high information density. Furthermore, van Leeuwen and Janssen (2019) reviewed 66 studies and found that teacher guidance was significantly associated with collaborative learning outcomes.

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In addition, King (2007) found that task characteristics had an impact on discussion quality in collaborative learning.

To achieve productive and successful collaborative learning, the collaborative learning task was considered an important factor. It was found that task design provided deep changes in mathematical thinking (Schwarz & Linchevski, 2007). Bower et al. (2017) found that task design had an impact on communication in collaborative learning. Schwarz and Linchevski (2007) tailored task design to create a cognitive conflict and promote impressive conceptual change. Therefore, the task design quality is closely related to collaborative learning quality.

However, task design is still neglected in the field of CSCL. Teachers and practitioners design collaborative learning tasks based on their experiences and assumptions. There is a lack of a holistic model or framework for CSCL task design. Bearing in mind few studies addressed how to design CSCL tasks, there is an urgent need for proposing an innovative model of task design. To this end, this study proposed a task design model to guide the design of CSCL tasks.

2.2 Literature Review

2.2.1 Task Characteristics

Task characteristics are considered as the antecedents of collaboration that affect collaboration in CSCL (Le et al., 2018). Previous studies revealed that task characteristics had an impact on social interaction quality in collaborative learning (Van Boxtel et al., 2000). De Hei et al. (2018) found that task characteristics were associated with learners' perceived increase in domain knowledge and they also suggested that tasks should be complex and authentic.

Task characteristics include task types, task complexity, and task interdependence. Task types include meaning-making or problem solving. Tasks can be open or closed, divergent or convergent, ill-structured or well-structured (Kapur & Kinzer, 2007). Acuña et al. (2018) found that learners who co-constructed concept maps achieved better learning performance than those who wrote expository summaries. For collaborative learning, task should be open, divergent, and ill-structured to stimulate learners' ideas from different perspectives.

Task complexity was very important for successful collaborative learning. Janssen and Kirschner (2020) revealed that effective collaboration occurred when a task was sufficiently complex to involve learners in collaborating together. It was found that groups outperformed individuals concerning learning efficiency when accomplishing high complex tasks (Janssen & Kirschner, 2020).

Interdependence means that group members can only reach their goals when the other group members reach their goals (Johnson & Johnson, 2009). Typically, there are two types of interdependence, namely means interdependence and outcome interdependence (Bertucci et al., 2016). Means interdependence includes resource interdependence, role interdependence, and task interdependence (Shimizu et al., 2020). In terms of means interdependence, information is divided among group members who have to collaborate to obtain the necessary information (Johnson & Johnson, 1999). Therefore, means interdependence could result in high quality interactions (Bertucci et al., 2012). Outcome interdependence means that collaborative partners are mainly interdependent in reaching a common goal (Janssen & Kirschner, 2020).

Task interdependence was conceptualized as the interconnections between tasks that cause the performance of one task to depend on other tasks (Van Der Vegt et al., 1998). Liden et al. (2006) found that group performance was moderated by task interdependence through 120 workgroups in six different organizations. Furthermore, Nebel et al. (2017) conducted an experiment to compare conditions with or without increased task interdependence through the jigsaw strategy and they found that task interdependence had beneficial effects on play performance and learning outcomes. The results were in line with Zambrano et al. (2019b) who believed that task interdependence was related to better learning outcomes.

2.2.2 Task Context

The importance of context had been emphasized in previous studies (Naidu & Oliver, 1999). Task context was related to the collaborative execution of tasks (Kreijns et al., 2003). Rick and Guzdial (2006) believed that task context was as important as collaborative tool design. The main reason was that task contexts drive the design of collaborative learning tool (Deeb, 2007). In addition, it was found that highly situated tasks promoted the recall and sharing experiences in similar contexts, because the context information activated episodic memories and schema in long-term memory (Jorczak & Bart, 2009). Social constructivist theory believed that authentic contexts contribute to increasing meaningful connections and the use of social resources (Ormrod, 2008). Greeno et al. (1993) found that increased context of discussion tasks made discussions more realistic. Furthermore, Kreijns et al. (2003) believed that both task context and non-task context were important because they can initiate social and psychological processes through formal and informal conversations. In addition, Arvaja (2011) differentiated three kinds of task contexts, including immediate and concrete context, socio-cultural context, and local context. Collaborative learning could be located in these three types of shared task contexts.

2.2.3 Problem Design

Problems are regarded as the important element of collaborative learning tasks. As Ablin (2008) stated that classrooms should be places of problem design rather than problem solving. Therefore, problem design was very crucial for high-quality collaborative learning. Problem design also plays an important part in achieving the learning objectives (Yeung et al., 2003). It was also found that problem statements had an impact on the students' learning and unsolved problems contributed to develop learners' independent self-directed learning and problem solving skills (Hung et al., 2013).

Previous studies investigated how to design problems in different contexts. For example, Hung (2006) proposed a 3C3R (Context, Content, Connection, Researching, Reasoning, Reflecting) model to design effective problems in problem-based learning (PBL). Furthermore, Hung (2009) applied 3C3R model to propose a 9-step PBL problem design process, including setting goals and objectives, conducting content analysis, analyzing context specification, generating problems, conducting problem affordance analysis, conducting correspondence analysis, conducting calibration processes, constructing reflection component, and examining inter-supporting relationships of 3C3R components. Furthermore, Zhang and Chu (2016) proposed a problem chain model, which includes eliciting previous experiences, challenges previous experiences, explanation, reflection, self-reasoning, and knowledge construction. These models provided good references for problem design in the CSCL context.

2.2.4 Task Assessment

Assessment plays a crucial role in guiding and driving learners toward knowledge acquisition (Macdonald, 2003). Assessment in CSCL includes three forms: assessing the individual, assessing the individual about the group, and assessing the group (Gress et al., 2010). Task assessment aims to evaluate the performance of collaborative learning tasks. The task assessment methods include formative and summative assessment as well as peer assessment. The data sources of task assessment include self-reported questionnaires, interview protocols, online discussion transcripts, group products, observations, videos, post-tests, and feedback (Gress et al., 2010). Furthermore, it was found that the provision of a task rubric promoted students' understanding of the task assessment criteria (Wiliam, 2007). Assessment criteria development and refinement through student responses was one promising pedagogy for teachers because it contributed to rich tasks (Ayalon & Wilkie, 2020). Therefore, how to assess tasks are a major concern for CSCL task design.

2.3 A Model of Designing CSCL Tasks

This study proposed a model of designing CSCL tasks, including task goals, task context, problems, sequences, resources, and assessment, as shown in Fig. 2.1.

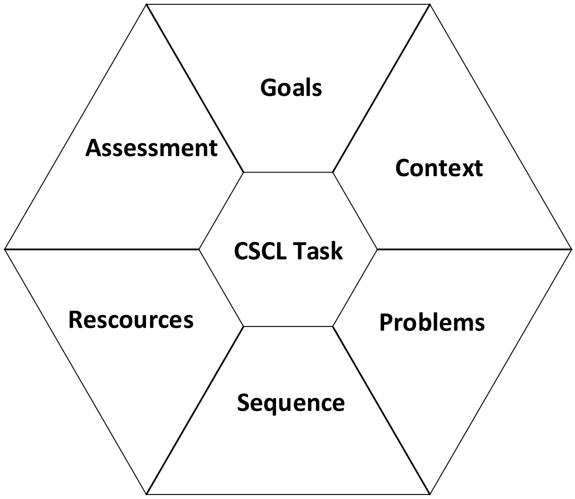

Fig. 2.1 The model of CSCL task design

2.3.1 Set Task Goals and Objectives

When designing a CSCL task, the first step is to set goals. Task goals should be in line with collaborative learning goals and objectives. Task goals include understanding concepts, principles, and procedures, acquisition of domain knowledge and skills, as well as the establishment of positive attitudes, emotions, values, and so on. Concepts, principles, procedures, domain knowledge, and skills can be represented through knowledge graphs to assist designers to conduct task design.

2.3.2 Design Context

When designing CSCL tasks, context should be designed elaborately and it should be clearly specified to promote meaningful learning. Learning context should be closely related to real-life to stimulate learners' learning interest and motivations. Task context can be designed and represented in different media, such as video, animation, music, pictures, and so on.

2.3.3 Problem Design

After designing task context, problems should be designed carefully to engage learners in solving problems. Usually, problems should be ill-structured problems or open-ended to stimulate learners' diverse ideas during CSCL. Different problems consist of problem chains, which should be closely related to authentic life to

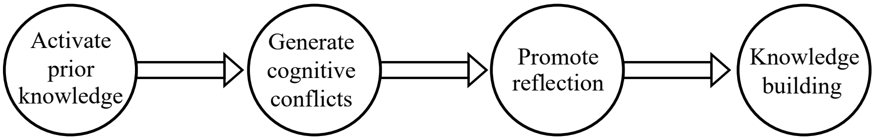

Fig. 2.2 The model of problem design

foster problem-solving skills. The model of problem design was proposed in this study, which includes activating prior knowledge, generating cognitive conflicts, promoting reflection, and knowledge building. Figure 2.2 shows the problem design model, which can guide to design high-quality problems.

2.3.4 Design Task Sequences

The task sequences include sub-task sequence and problem sequence. When designing a sub-task sequence, it should be arranged from simple to difficult. In addition, different sub-tasks should be interdependent to promote collaboration. Furthermore, problems within each sub-task should be designed carefully. Usually, the simple problems are arranged first, and then the difficult problems followed.

2.3.5 Develop Task Resources

Collaborative learning task resources include a task list, hardware, software such as an online collaborative learning platform, and various kinds of learning materials. In addition, teachers and peers are considered as important and valuable resources. If learners have difficulties when they complete tasks, they can ask for help from teachers and peers. They can also discuss with peers to collaboratively solve problems.

2.3.6 Design Assessment Methods

How to evaluate task performance should be designed ahead of time. Task performance should be evaluated in an objective manner to promote reflection and improvement. Task assessment methods should indicate task outcomes, assessment criteria, durations, requirements, and standards. Usually, the task outcomes are group products, including proposals, plans, models, and so on. The assessment criteria should clearly describe the categories of assessment and scores. Durations also should be clearly specified so that students can complete the tasks before the deadline. In addition, some requirements or standards should also be specified in detail.

2.4 The Two Cases

This section will illustrate how to design computed-supported collaborative learning tasks using two cases. The first case was about making an intelligent voice broadcast rangefinder. The second case was about developing an intelligent destination board. The following sections will illustrate the two collaborative learning tasks in detail.

2.4.1 The First Case

Step 1: Set task goals and objectives

The task goals and objectives include understanding the principles about how an ultrasonic sensor measures distances, acquiring how to output voice through collaboratively programming, and developing an intelligent voice broadcast rangefinder.

Step 2: Design task contexts

The task context was as follow:

Suppose you are an engineer and you need to build a house. Before you build a house, you have to measure the distances among different houses in the district. However, there are many houses in this district. If you measure by a flexible rule, it will take a long time. Thus, you want to develop an intelligent voice broadcast rangefinder to measure distances automatically.

Step 3: Problem design

To develop an intelligent voice broadcast rangefinder, the following problems need to be solved one by one:

1. How to assemble an intelligent voice broadcast rangefinder based on the existing hardware?
2. What is the functionality of an ultrasonic sensor?
3. How to measure distances through an ultrasonic sensor?
4. What are the principles of ultrasonic rangefinder?
5. What are the major differences between "if…else…" and "switch…case…"?
6. How to output voice through programming?
7. How to output "The distance is centimeter" through programming?
8. How to test the intelligent voice broadcast rangefinder?

Step 4: Design sequences

This collaborative learning task included two sub-task sequences. The first was to assemble the broadcast rangefinder and the second was to output voice through programming and make an intelligent voice broadcast rangefinder. Obviously, these two sub-tasks were arranged in the correct order and they were interdependent. If learners cannot assemble the broadcast rangefinder, they will not program further. In addition, the problem sequence should be also arranged from the simple to difficult.

Step 5: Develop task resources

The task resources include a textbook, the hardware of the intelligent voice broadcast rangefinder, a programming platform, a task list, learning materials, scaffolding, teachers, and group members. These resources are prepared when designing collaborative learning tasks.

Step 6: Assessment methods

The task product was an intelligent voice broadcast rangefinder. The assessment dimensions include feasibility, correctness, and originality. The assessment criteria are shown in Table 2.1.

Table 2.1 The assessment criteria

Items	Descriptions	Scores
Feasibility	The intelligent voice broadcast rangefinder should output the voice when measuring distances.	35
Correctness	The intelligent voice broadcast rangefinder can measure the correct distances.	35
Originality	Learners make an original intelligent voice broadcast rangefinder.	30

2.4.2 The Second Case

Step 1: Set task goals and objectives

The task goals and objectives include understanding the concepts, characteristics, principles of speech recognition, acquiring how to identify male voice and female voice, acquiring how to connect steering engine and main control panel as well as how to control the direction of steering engine through voice.

Step 2: Design task context

The task context was as follow:

Suppose there will be an international conference and you are a volunteer of the conference. XiaoWang's task was to guide participants into different buildings and meeting rooms. However, there will be hundreds of participants who will attend this conference. If XiaoWang guide them one by one, it will take a long time and XiaoWang are also very tired. Please help XiaoWang to develop an intelligent destination board to guide participants automatically.

Step 3: Problem design

To develop an intelligent destination board, the following problems need to be solved one by one:

1. What is speech recognition and what are the major characteristics of speech recognition?
2. How to identify male voice and female voice?

3. What are the functionalities of a steering engine and knob?
4. How to initialize a steering engine?
5. How to recognize speech by programing?
6. How to adjust the volume by programing?
7. How to test the intelligent destination board?

Step 4: Design sequences

This collaborative learning task included two sub-task sequences. The first was to assemble the intelligent destination board and the second was to recognize male voice and female voice through programming and make an intelligent voice destination board. Obviously, these two sub-tasks have been arranged in correct order and they were interdependent. If learners cannot assemble the destination board first, they cannot program further. The problems have been arranged in the appropriate order.

Step 5: Develop task resources

The task resources include a textbook, the hardware of the intelligent voice destination board, a programming platform, a task list, learning materials, scaffolding, teachers, and group members.

Step 6: Assessment methods

The task product was an intelligent voice destination board. The assessment dimensions include feasibility, correctness, and originality. The assessment criteria are shown in Table 2.2.

Table 2.2 The assessment criteria

Items	Descriptions	Scores
Feasibility	The intelligent voice destination board can guide the direction and output voice.	35
Correctness	The intelligent voice broadcast rangefinder can identify male voice and female voice as well as indicate the direction correctly.	35
Originality	Learners make an original intelligent voice destination board.	30

2.5 Discussion and Conclusions

This study proposed a collaborative learning task design model with six elements, including task goals, task context, problems, sequences, resources, and assessment. This model was illustrated by six steps in depth. Each element was equally important for high-quality tasks and productive collaborative learning. In addition, the problem design model was also proposed to guide the design of valuable problems. Furthermore, two collaborative learning cases about artificial intelligence were conducted to validate the proposed model. The proposed models shed light on how to design high-quality tasks and provided valuable references for teachers and practitioners. These are also the main contributions of the present study.

This study had several implications for teachers, researchers, and practitioners. First, collaborative learning tasks were very important for knowledge and skills acquisitions. Therefore, tasks should be designed elaborately before collaborative learning. Second, collaborative learning tasks should contribute to achieving learning goals and objectives. That is to say task goals should be in line with collaborative learning goals. It is suggested that teachers and practitioners should double-check whether or not the collaborative learning task goals are consistent with collaborative learning goals and objectives. Third, this study proposed a task design model with six elements. These six elements play a crucial role for successful collaborative learning and they cannot be neglected in practice. Fourth, it is suggested that an analytic-driven design approach should be adopted to design and optimize these six elements. As Mangaroska and Giannakos (2018) revealed that learning analytics and learning design share common goals as well as learning analytics should align with learning design. Thus, task design is an iterative process and it should be optimized continually based on learning analytics results. Task design decisions can be reached through analysis and reflections of the collaborative learning process and learning outcomes.

However, the present study had several limitations and caution should be made when generalizing the results. First, the relationships among the six elements have not been examined. Future study will investigate how these six elements interrelate with each other. Second, this study only conducted two cases to validate the proposed model. Future studies will expand the sample size to conduct empirical studies to validate and optimize the model.

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Chapter 3
Learning Analytics for Computer-Supported Collaborative Learning Design

Abstract With the development of learning technology, learning analytics has been used to analyze lots of data about learners to improve learning performance and inform learning design. However, teachers and practitioners still found it is challenging to integrate learning analytics into computer-supported collaborative learning (CSCL) design. This chapter developed a collaborative learning analysis framework to illuminate how to analyze collaborative learning. The proposed framework includes six elements, namely analysis of cognitions, metacognitions, behaviors, emotions, social network relationships, and alignment. A case study was conducted to validate the proposed framework and illustrate how analysis results influence collaborative learning design decisions. This framework also contributed to inform and optimize computer-supported collaborative learning design.

3.1 Introduction

Online collaborative learning has been paid more and more attention in recent years. Learners conducted online collaborative learning to collaboratively build knowledge, solve problems, and improve learning performance. Successful online collaborative learning should be active coordination of group dynamics (Kreijns et al., 2003), mutual engagement of the learners (Resta & Laferrière, 2007), and maximization of efficient interactions through a shared environment (Abrami et al., 2011).

To achieve successful online collaborative learning, the efficiency of online collaboration should be monitored and analyzed in time (Saqr et al., 2018). A lot of data generated during online collaborative learning, including log frequency, discussion transcripts, group products, and so on. The large amounts of data need to be analyzed to provide insights into how online collaborative learning occur and evolve over time. The analysis of data can also detect the deficiency of collaborative learning design. Lockyer et al. (2013) revealed that learning analytics can evaluate whether a learning design achieves the expected purpose.

Previous studies on learning analytics in collaborative learning focused on the analysis of social network (Saqr et al., 2020a), identify successful learners (Kotsiantis

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https://doi.org/10.1007/978-981-16-1718-8_3

et al., 2013), visualized students' cognitive activities (Van Leeuwen et al., 2015), and so on. It still lacks integrated analysis of online collaborative learning processes and outcomes. Very few studies pay attention to the analysis of the alignment between design and enactment. This study aims to propose a comprehensive analysis framework about online collaborative learning to provide feedback and shed light on how to optimize collaborative learning.

3.2 Literature Review

3.2.1 Learning Analytics

Learning analytics is conceptualized as the collection, analysis, measurement, and presentation of data about learners for optimizing learning (Siemens & Gasevic, 2012). Learning analytics focused on the relationships between the learners and the learning environments (Vieira et al., 2018). Learning analytics aims to model student behaviors or emotions, predict dropout or learning performance, promote social interactions or reflection, and recommend learning resources (Papamitsiou & Economides, 2014; Verbert et al., 2012). Furthermore, Vieira et al. (2018) defined visual learning analytics as "the use of computational tools and methods for understanding educational phenomena through interactive visualization techniques." Visual learning analytics contributes to providing feedback and improving the instructional materials (Vieira et al., 2018) as well as enriching the learning process (Ritsos & Roberts, 2014).

Recently, learning analytics technology has been widely adopted in the field of education. For example, Zhang et al. (2018) adopted learning analytics technology to analyze the online learning logs of 1,088 students from 22 classes in terms of login behaviors, interactive behaviors, quizzes, resource utilization, and academic achievement. Lu et al. (2018) applied learning analytics for the early prediction of learners' final academic performance in a blended calculus course. The real data were collected from video-viewing behaviors, homework, quiz scores, out-of-class practice behaviors, and after-school tutoring. They found that students' final academic performance could be predicted when only one-third of the semester had elapsed.

In addition, some researchers sought to conduct multimodal learning analytics to shed light on learning processes and outcomes. For example, Noroozi et al. (2019) employed multimodal learning analytics technology to get a better understanding of the regulation of learning. They collected, analyzed, and visualized video data, log data, and sensor data to provide for researchers, teachers, and learners. Riquelme et al. (2019) adopted multimodal learning analytics to develop a computational environment to both analyze and study collaboration on discussion groups. Vujovic et al. (2020) adopted multimodal learning analytics to analyze collaborative problem-solving processes and found that round tables lead to higher levels of on-task participation.

To sum up, quite a number of studies employed learning analytics to analyze learners' behaviors or gestures to provide feedback for teachers or learners. It is a lack of integrated analysis of collaborative learning processes and outcomes as well as the analysis of alignment between collaborative learning design and enactment.

3.2.2 Analysis of Collaborative Learning

Collaborative learning processes and outcomes can be analyzed in different ways, including content analysis methods, social network analysis method, lag sequential analysis method, epistemic network analysis method, and so on. For example, Zheng et al. (2019) adopted content analysis method to analyze group metacognitive behaviors. Garcia and Jung (2020) employed content analysis method to analyze interview responses after learners participated in online collaborative learning. In addition, Xie et al. (2018) adopted social network analysis method to detect leadership in online collaborative learning. Saqr et al. (2020b) employed social network analysis method to analyze the participation and social dimensions of collaborative learning.

Furthermore, some researchers integrated multiple analysis methods to shed light on collaborative learning processes and outcomes. For example, Zhang et al. (2017) combined content analysis method, social network analysis method, and lag sequential analysis method to analyze interactive networks and social knowledge construction behavioral patterns in primary school teachers' online collaborative learning activities. Swiecki et al. (2020) adopted the epistemic network method to analyze individual contributions in collaborative problem solving and they found that the epistemic network method was a more powerful tool than coding and counting approaches.

However, previous studies only focused on some aspects of collaborative learning, there is still a lack of holistic analysis of collaborative learning processes and outcomes. To close this gap, the present study sought to propose an analysis framework about collaborative learning to shed light on the development and evolution of cognition, metacognition, behaviors, emotions, and social network during collaborative learning.

3.2.3 Learning Design

Koper (2006) believed that learning design is "the description of the teaching-learning process that takes place in a learning unit." Learning design is also conceptualized as "the application of methods, resources, and theoretical frameworks to achieve a particular pedagogical goal in a given context" (Mangaroska & Giannakos, 2018; Mor & Craft, 2012). More specifically, learning design describes "the sequence of learning tasks, resources, and supports" (Lockyer et al., 2013). Learning design is considered as an activity and the product of that activity (Mor & Craft, 2012).

Learning design established pedagogical objectives and plans, which can be evaluated against the outcomes obtained through learning analytics (Lockyer et al., 2013). Therefore, learning design and learning analytics are closely related to each other. However, research is missing to examine what learning analytics is used to inform learning design. To close this research gap, the present study aims to propose a learning analytics framework about online collaborative learning to optimize learning design.

3.3 An Analysis Framework About Collaborative Learning

This study proposed an analysis framework of collaborative learning, as shown in Fig. 3.1. This framework includes six elements, namely analysis of cognitions, metacognitions, behaviors, emotions, social network relationships, and alignment. The analysis results can be adopted to optimize collaborative learning design and improve collaborative learning performance. The following section will illustrate the framework one by one.

Step 1: Analysis of cognition

Analysis of cognition includes analysis of collaborative knowledge building and group products as well as individual contributions. The analysis of collaborative knowledge building can adopt the IIS-map-based analysis method proposed by Zheng et al. (2012). The level of collaborative knowledge building is measured through the activation quantity of the knowledge graph. Group products can be analyzed

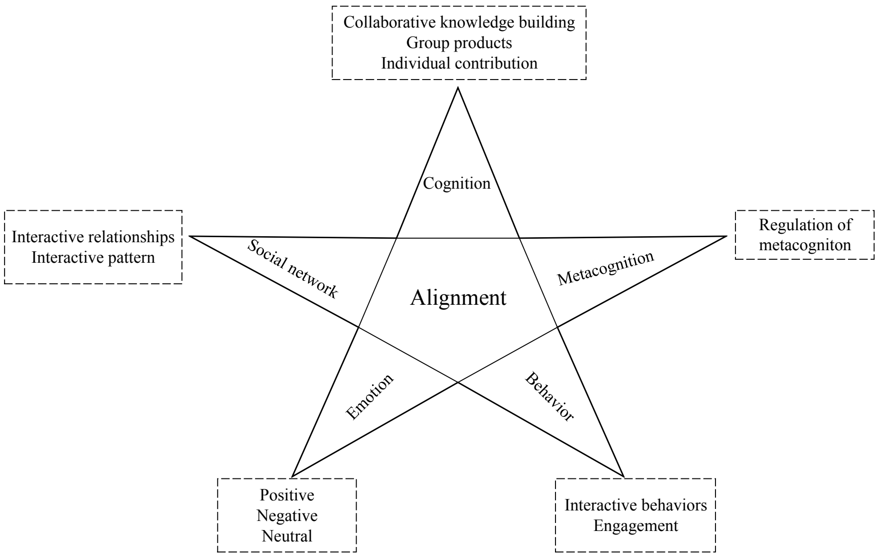

Fig. 3.1 The analysis framework of collaborative learning

based on predefined criteria. The individual contribution was analyzed through the IIS-map-based method and it can be measured through individual activation quantity. If researchers are interested in knowledge and skill acquisition, pre-test and post-test can be adopted to analyze learners' knowledge gains and cognition level. However, pre-test and post-test only examined learning outcomes rather than learning processes. It is suggested that the IIS-map-based analysis method can be adopted to analyze collaborative knowledge building processes.

Step 2: Analysis of metacognition

Analysis of metacognition aims to get a better understanding of how learners regulate their metacognitions during CSCL. The metacognitive analysis focus on how each group members or the whole group set goals, make plans, monitor and control as well as reflect and evaluate. Metacognition can be analyzed at the individual and group level. The content analysis method or thinking aloud method can be adopted when analyzing metacognition.

Step 3: Analysis of behaviors

Interactive behaviors need to be analyzed in-depth to shed light on how learners collaborate with each other. Interactive behaviors can be analyzed from different perspectives, such as engagement, role behaviors, regulated behaviors, and so on. Interactive behaviors can be analyzed in different ways, such as content analysis method, lag sequential analysis method, and so on.

Step 4: Analysis of emotions

Learners' emotions should be analyzed to provide insights into learners' perceptions during collaborative learning. Emotions can be categorized into positive, negative, and neutral (Pang & Lee, 2008). Emotions can be analyzed through a manual or automatic analysis method. For example, two coders can adopt a content analysis method and code online discussion transcripts manually to understand learners' emotions. To achieve automatic analysis, the machine learning method and deep neural network method can be adopted to automatically classify emotions.

Step 5: Analysis of social network relationships

Collaborators' social network relationships need to be analyzed to shed light on interactive relationships and interactive pattern. The social network analysis method is usually employed to analyze interactive relationships and interactive pattern during collaborative learning. Many popular software such as Gaphi, Ucinet, and Netdraw can be used to conduct social network analysis.

Step 6: Analysis of alignment

The analysis of alignment focuses on the alignment between collaborative learning design and enactment. The purpose of alignment analysis is to analyze the deficiency of collaborative learning design, advance technological knowledge about design, and improve learning performance (Zheng et al., 2020). A previous study revealed that the range of activated knowledge, the degree of knowledge building, the interactive approach, and interaction path graphs can be adopted to analyze the alignment between design and enactment (Zheng et al., 2020). In fact, the analysis of alignment can be conducted from the perspectives of cognition, metacognitions, behaviors, emotions, and social network relationships. Therefore, it is located in the center of the framework.

3.4 The Case Study on Collaborative Learning

3.4.1 Collaborative Learning Tasks

This case study aims to validate the proposed analysis framework through a collaborative problem-solving case. The collaborative learning task was to crawl the pages of Baidu Wikipedia and Weibo through a web crawler as well as generate word cloud graph based on the texts of Weibo. This task aims to improve learners' problem-solving skills through CSCL. Three postgraduate students participated in this study for more than three hours. A popular social media tool (QQ), an online collaborative writing tool, and Python 3.7 were adopted to support online collaborative learning. The group members assigned three roles by themselves, including a group leader, a recorder, and an engineer. The collaborative learning design plan is shown in Table 3.1. The following section will explain the analysis results one by one.

Table 3.1 The collaborative learning design plan

Elements	Details
Goals	The collaborative learning goal was to acquire the technology about web crawler and how to crawl the homepages of Baidu Wikipedia and Weibo through Python.
Tasks	XiaoMing learned about programming through Python and he wanted to crawl the pages of Weibo. However, he found that Weibo need to login and the pages of Weibo cannot be crawled directly. Please help XiaoMing to crawl the pages of Weibo through Python.
Interaction	Group members conducted online discussion through the social media tool and co-writing tool to complete the task. The recommended role assignment includes the group leader, the engineer, and the recorder. The group leader was responsible for organizing, negotiating, and summarizing. The engineer was responsible for programming and the recorder was responsible for recording and discussion during the whole collaborative learning process. In addition, the interactive strategies include brainstorming, discussion, and argumentation.
Resources	Learning resources include learning materials about Python and web crawler.
Assessment	The group product includes source codes and a word cloud graph. The assessment criteria focus on the precision of source codes and word cloud graph.
Implementation	All of the group members conducted online collaborative learning for three hours.

3.4.2 The Analysis of Cognition

First, the collaborative knowledge building level was analyzed through the IIS-map-based analysis method. The results indicated that the level of collaborative knowledge building was 235.36. The knowledge elaboration level reached 435.59 and knowledge convergence achieved 101.04.

Second, the individual contribution was analyzed through the activation quantity. It was found that the contribution of group leader, engineer, and recorder reached 89.70, 60.19, 33.65, respectively. Therefore, the group leader contributed the most among the three members.

Third, the group product included source codes and a word cloud graph. The group product was evaluated through the precision of source codes and word cloud graph. The results indicated that the precision of source codes reached 67 and the precision of word cloud achieved 25, respectively. Thus, the total score of the group product was 92.

3.4.3 The Analysis of Metacognition

This study analyzed individual metacognition in terms of setting goals and plans, monitoring as well as reflection and evaluation. The results indicated that setting goals and plans reached 48.8%. Monitoring and controlling accounted for 39.2%. Reflection and evaluation only accounted for 5.6%. Therefore, this group demonstrated more planning and monitoring than reflection and evaluation.

3.4.4 The Analysis of Behaviors

First, each group member's learning engagement was analyzed through the numbers of information flows. It was found that the group leader output 63 information flows, the engineer output 28 information flows, and the recorder output 34 information flows.

Second, the behaviors of the group leader, the engineer, and the recorder were analyzed in depth. It was found that the group leader performed the expected responsibilities and the behaviors of organizing, negotiating, and summarizing reached 100%. The monitor also performed the expected responsibilities and the behaviors of programming achieved 100%. However, the behavior of the recorder only included recording, which accounted 67.6%. The recorded did not discuss with group members.

3.4.5 The Analysis of Emotions

The group members' emotions were analyzed and the results indicated that positive emotions achieved 90.4%, negative emotions reached 2.4%, and neutral emotions accounted for 7.2%. Thus, this group collaborated in a positive and harmonious atmosphere.

3.4.6 The Analysis of Social Network Relationships

The interactive relationships of the three participants are shown in Fig. 3.2. Since only three group members participated in this study, the interactive relationships and pattern were simple. The interactive frequency of XiaoCai and XiaoLi achieved the most, followed by XiaoLi and XiaoNiu.

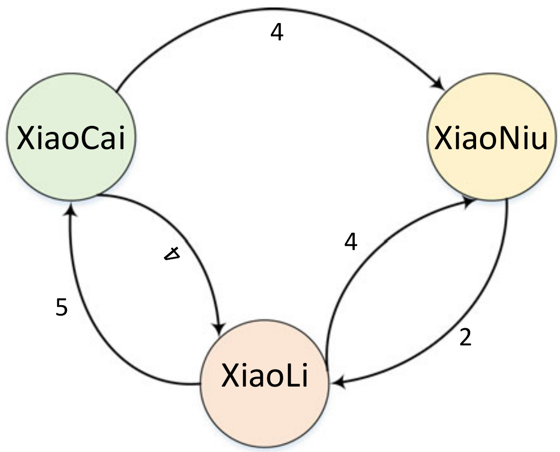

Fig. 3.2 The social network relationships

3.4.7 The Analysis of Alignment

First, the alignment of the range of activated knowledge was calculated and the results indicated that it reached 0.913. Second, the alignment of knowledge building was calculated and the findings revealed that it achieved 0.783. Figures 3.3 and 3.4 show the target knowledge graph and the actual knowledge graph generated by this group. Third, the actual interactive path graph was analyzed and the findings indicated that the interactive path was a little bit different from the expected path. Figure 3.5 show the interactive path graph. The main reason was that some group members lacked prior knowledge about Python and web crawler.

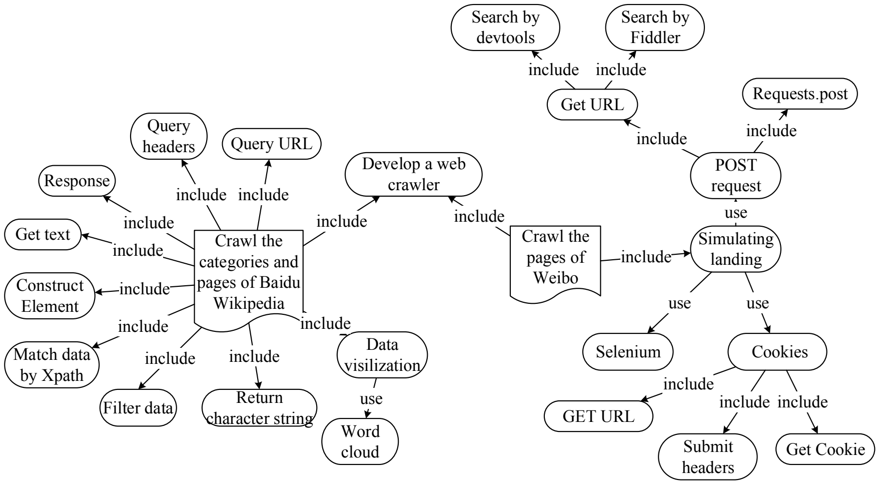

Fig. 3.3 The target knowledge graph

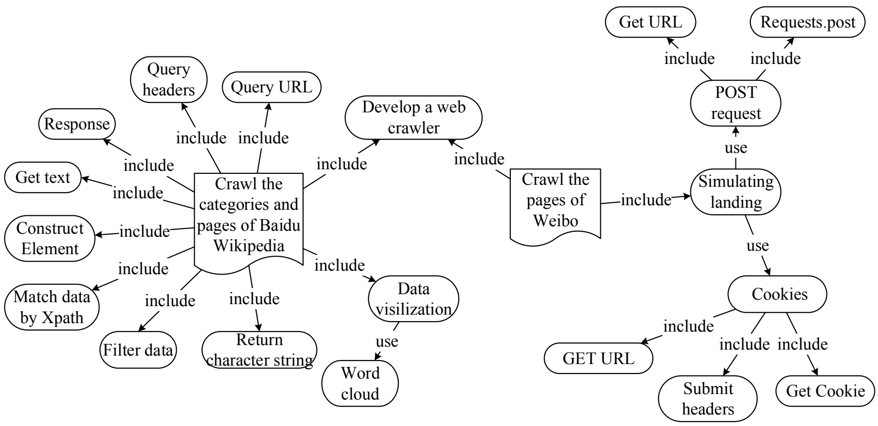

Fig. 3.4 The knowledge graph of the group

3.4.8 Optimization Design Based on Learning Analytics Results

After analyzing the cognitions, metacognitions, behaviors, emotions, social network relationships, and alignment, the design deficiency was found and the design plan of collaborative learning needed to be refined and optimized further. First, collaborative learning task should be elaborated to propose more questions and promote reflection. Second, the role assignment needs to be revised to keep the responsibilities of each member balance. Third, more learning materials and scaffolding should be provided for learners to co-construct knowledge in depth. Table 3.2 is the optimized design plan of collaborative learning.

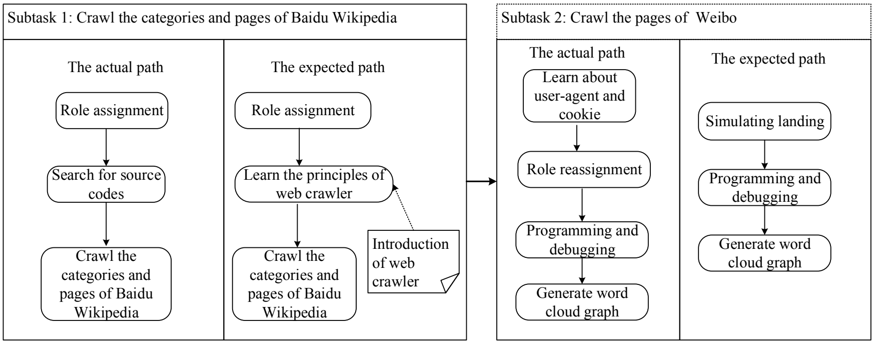

Fig. 3.5 The interactive path graph

Table 3.2 The optimized design plan of online collaborative learning

Elements	Details
Goals	The collaborative learning goal was to acquire the technology about web crawler and how to crawl the homepages of Baidu Wikipedia and Weibo through Python.
Tasks	XiaoMing learned about programming through Python. One day, he wanted to crawl the pages of Baidu Baike and Weibo. However, he found that Weibo need to login and the pages of Weibo cannot be crawled directly. Please help XiaoMing to crawl the pages of Baidu Baike and Weibo through Python as well as generate the word cloud graph. • How to crawl the pages of Baidu Baike through Python? • How to crawl the pages of Weibo through Python? • What is the difference in crawling the pages of Baidu Baike and Weibo? • How to generate the word cloud graph based on the crawled texts?
Interactions	Group members conducted online discussion through the social media tool and co-writing tool to complete the task. The recommended role assignment includes the group leader, the engineer, and the recorder. The group leader was responsible for organizing, negotiating, and summarizing. The engineer was responsible for programming. The recorder was responsible for recording and debugging during the whole collaborative learning process. In addition, the interactive strategies include brainstorming, discussion, and argumentation.
Resources	Learning resources include learning materials about Python and web crawler. The prior knowledge about Python and web crawler were also provided for learners. In addition, some programming samples were provided for learners.
Assessment	The group product includes source codes and a word cloud graph. The assessment criteria focus on the precision, originality, and completeness of source codes and word cloud graph. Some samples were provided for reference.
Implementation	All of the group members conducted online collaborative learning for three hours. Teachers provided scaffolding when necessary.

3.5 Discussion and Conclusions

This study proposed a collaborative learning analysis framework, which included analysis of cognitions, metacognitions, behaviors, emotions, social network relationships, and alignment. A case study was also conducted to validate the proposed framework in the present study. The findings indicated that this framework was feasible and informative for the analysis of collaborative learning processes and outcomes. The framework highlighted the importance of analysis of alignment between design and enactment. The proposed framework also provided insights on how to analyze online collaborative learning systematically.

The present study had several implications for researchers, teachers, and practitioners. First, analysis of cognitions, metacognitions, behaviors, emotions, social network relationships, and alignment can be automatically conducted with the help of artificial intelligence technologies. Artificial intelligence technologies that simulate human intelligence to make decisions, judgments, or predictions can analyze data and provide personalized feedback and support for teachers, learners, and or policymakers (Hwang et al., 2020). Therefore, researchers can design and develop intelligent analytical tools to analyze automatically learners' cognitions, metacognitions, behaviors, emotions, social network relationships. Consequently, learners can also get instant analysis results and real-time feedback to improve learning performance further.

Second, teachers and practitioners need to provide interventions when necessary based on learning analytical results. For example, teachers and practitioners can send kind reminders when there is lack of interactions. As Snderlund et al. (2019) reported the overall success of the intervention based on learning analytics after they reviewed 11 studies on learning analytics interventions. Wong and Li (2020) also found that learning analytics intervention contributed to increasing learning performance, offering personalized feedback and improving retention. Therefore, learning analytics results serve as important evidence on offering interventions for learners.

Third, teachers and practitioners need to optimize collaborative learning design according to learning analytics results. For example, when teachers and practitioners found there were knowledge gaps and negative emotions during collaborative learning, collaborative learning tasks maybe need to be refined. Meanwhile, cognitive and emotional scaffolding should be provided in collaborative learning. Mangaroska and Giannakos (2018) also reported the convergence and synergies between learning analytics and learning design after they reviewed 43 studies. Therefore, learning analytics should also align with learning design to improve efficiency and effectiveness (Lockyer et al., 2013).

The present study had several limitations that should be noted. First, only one case study was conducted to validate the proposed framework. The empirical study will be conducted to refine the analysis framework in a future study. Second, the current analysis mainly depended on coding manually. Future studies will develop intelligent tools through artificial intelligence technologies to analyze and visualize learning analytics results automatically.

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Chapter 4
Design and Optimization of Scaffolding in Computer-Supported Collaborative Learning

Abstract Collaborative learning is a very effective pedagogy. However, the effectiveness of collaborative learning cannot be achieved spontaneously and it is necessary to provide the support of scaffolding. This study designed and optimized scaffolding based on the data-driven approach in a computer-supported collaborative learning context. Three rounds of collaborative learning were conducted and the scaffolding was revised and optimized twice to examine the effectiveness. The findings revealed that collaborative knowledge building levels and group product quality were improved after the optimization of scaffolding. The results and implications for teachers and practitioners were also discussed in depth.

Keywords Collaborative learning · Cognitive scaffolding · Metacognitive scaffolding

4.1 Introduction

Computer-supported collaborative learning (CSCL) has been widely used in the field of education. It was found that CSCL was a very effective and promising method for improving critical thinking skills (Loes & Pascarella, 2017) and problem-solving abilities (Retnowati et al., 2017) as well as motivating motivations (Serrano-Cámara et al., 2014). However, the productive outcomes resulting from CSCL cannot emerge without scaffolding (Winne et al., 2013). Scaffolding was originated from Vygotsky's zone of proximal development (Wood et al., 1976). Van de Pol et al. (2010) proposed that scaffolding can be classified into cognitive, metacognitive, and affective scaffolding. Scaffolding can be divided into hints, questions, feedbacks, instructions, explanations, and models (Van de Pol et al., 2010).

Scaffolding has been widely applied in the field of CSCL. For example, Shin et al. (2020) developed meaning-negotiation scaffolding and position-negotiation scaffolding in CSCL environment and they found that fading meaning-negotiation scaffolding and provision of position-negotiation achieved the best learning performance. In addition, Hsieh (2017) found that online resources were critical scaffolding for promoting interactions and knowledge construction in collaborative language

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learning. Lin et al. (2020) developed a scaffolding-based collaborative problem-solving environment and they found that learners in the scaffolding mind tool group showed higher learning performance and more diverse cognitive levels.

Previous studies indicated that providing scaffolding can promote productive interactions and improve learning performance in CSCL field (Vogel et al., 2017; Zheng et al., 2019). However, how to design, implement, and optimize scaffolding in CSCL is still lacking. This chapter developed and optimized scaffolding based on the data-driven approach in CSCL environment. This new approach will also be applied and validated in an authentic CSCL setting. The following sections will illustrate how to design and implement scaffolding in depth.

4.2 Literature Review

Previous studies revealed that learners need scaffolding to engage in collaborative learning and generate productive outcomes (Belland et al., 2013). Learners also need scaffolding to support group regulation at cognitive, emotional, and metacognitive levels (Järvelä et al., 2014). It was found that cognitive scaffolding was very useful for successful collaborative learning (Cooper & Robinson, 2014). Vogel et al. (2017) found that socio-cognitive scaffolding with computer-supported collaboration scripts had a small positive effect on domain-specific knowledge and a large positive effect on collaboration skills through the meta-analysis of 22 studies. Hou and Keng (2020) found that cognitive scaffolding promoted the problem-solving process during collaborative learning. Furthermore, pre-work activities were used as socio-cognitive scaffolding in asynchronous online discussions and students show deep learning with the help of socio-cognitive scaffolding during online discussions (Koszalka et al., 2021).

Additionally, Hannafin et al. (1999) believed that metacognitive scaffolding aims to provide guidance through domain-general support. In the CSCL context, metacognitive scaffolding promoted social interactions (Molenaar et al., 2014), positive interdependence, group productivity (Kwon et al., 2013), and synergy (Siegel, 2012). Metacognitive scaffolding contributed to improving group performance and group metacognitive behaviors in CSCL (Zheng et al., 2019). Zheng et al. (2019) developed group metacognitive scaffolding in CSCL environments, which promote planning, monitoring, and evaluation and reflection during CSCL. They found that group metacognitive scaffolding had significant impacts on group metacognitive behavioral transition and group performance.

Furthermore, some researchers adopted motivation scaffolding to facilitate CSCL. Motivation scaffolding aims to enhance motivational factors such as self-efficacy, autonomy, relatedness, interest, or perceptions (Belland et al., 2013). It was found that motivational scaffolding in the form of synchronous online group meetings and instructor office hours promoted course and school term performance (Tuckman, 2007). In addition, emotional scaffolding also played a more and more important role in collaborative learning. Perceived trust and safety as well as empathetic solidarity are considered as emotional scaffolding, which can promote long-term collaboration (Eteläpelto & Lahti, 2008).

In the CSCL context, scaffolding can be presented through scripts, questions, hints, prompts, and tools. For example, Fischer et al. (2013) believed that scripts can smooth communication and promote high-level socio-cognitive activities in CSCL. Näykki et al. (2017) adopted a regulation macro script to facilitate socio-cognitive and socio-emotional monitoring during collaborative learning. In addition, Heflin et al. (2017) facilitated mobile collaborative learning through discussion prompts. Lin and Reigeluth (2016) adopted wiki to support whole-class collaborative knowledge building and small-group project learning. However, previous studies only compared the effects of scaffolding in collaborative learning. It is still a lack of studies on refining and optimizing scaffolding in collaborative learning. This study aims to investigate how to optimize scaffolding based on the data-driven approach in CSCL context.

4.3 Method

4.3.1 Participants

This study enrolled nine graduate students to participate in three rounds of online collaborative learning. The participants were female and the average age was 23 years old. For each round of collaborative learning, one group of three students participated in online collaborative learning. These three students never collaborated before. The pre-test results indicated that there was no difference in prior knowledge among these three groups.

4.3.2 The Collaborative Learning Task

The topic of online collaborative learning was personalized learning. The collaborative learning task was to design an instructional plan for a unit entitled "Life in the Future." This unit was from an English textbook for high school students. Table 4.1 shows the details of the collaborative learning task, including learning objectives, tasks, interactive strategies, learning resources, and assessment method. Table 4.2 shows the assessment criteria.

Table 4.1 The collaborative learning design plan

Items	Descriptions
Collaborative learning objectives	1. Get a better understanding of personalized learning. 2. Apply personalized learning principles and strategies to conduct instructional design.
Collaborative learning tasks	Teacher Wang will teach English to high school students. The topic of the unit is "Life in the Future." Please help teacher Wang to conduct instructional design. You should discuss the following questions during design processes: 1. How to design personalized instructional plans based on different levels of prior knowledge? 2. How to design personalized learning activities based on learners' cognitive style? 3. How to make use of artificial intelligence to support personalized learning? The group product is an instructional design plan. Please adopt ShiMo document to collaboratively edit the document with group members.
Interactive approaches	The interactive methods include online discussion, brainstorming, and argumentation. The interactive rules include: conducting role assignment before collaborative learning, avoiding being off-topic, negotiating and solving conflicts politely. Don't quarrel with peers. It is suggested that the group leader should organize and manage the whole online collaborative learning process and double-check group products. The monitor should monitor the whole collaborative learning process, ask questions, and evaluate others' ideas. The recorder should be responsible for searching for information and recording the main ideas.
Learning resources	Learning resources include learning materials about personalized learning and collaboratively editing software.
Assessment method	The teachers evaluated the group products based on the following criteria (see Table 4.2).

4.3.3 Procedure

This study conducted three rounds of online collaborative learning through a social media tool. Participants conducted online collaborative learning for three hours in each round. The scaffolding was provided for learners in each round of collaborative learning. The scaffolding was revised and optimized based on the analysis results after each round of collaborative learning.

Table 4.2 The assessment criteria

Dimension	Sub-dimension	Scores
Instructional objectives	Set instructional objectives based on learners' characteristics.	20
	Instructional objectives are appropriate, reasonable, and measurable.	10
Instructional emphasis	The instructional emphasis is correct and appropriate.	10
Instructional processes	The instructional process is complete.	10
	Set up a personalized learning context.	10
	Design personalized learning activities based on learners' cognitive style.	20
	Make use of artificial intelligence to support personalized learning.	10
	The instructional process is coherent and complete.	10

4.3.4 Design and Optimization of Scaffolding

In the present study, different types of scaffolding were provided for learners in three rounds of collaborative learning. Initially, only cognitive scaffolding was provided in the first round of collaborative learning. And then, the online discussion transcripts, collaborative knowledge building level, and group products were analyzed and evaluated. The scaffolding was further optimized based on the analysis results of the first round of collaborative learning. After conducting the second round of collaborative learning, the scaffolding was optimized further based on the analysis results of the second round of collaborative learning. Finally, the third round of collaborative learning was conducted to validate the optimized scaffolding. Table 4.3 shows the provided scaffolding of three rounds.

4.3.5 Data Analysis Method

The collaborative knowledge building level was analyzed through the analysis method developed by the authors. This method was an IIS-based analysis method and it includes three steps (Zheng et al., 2012). First, draw the target knowledge map. Second, segment discussion transcripts based on the rules. Third, calculate the knowledge building, knowledge elaboration, and knowledge convergence. In addition, the group products were instructional design plans and all of the group products were evaluated by two researchers according to the aforementioned assessment criteria. The interrater reliability achieved 0.92, indicating excellent reliability.

Table 4.3 The scaffolding of three rounds

Rounds	The scaffolding
The scaffolding provided in the first round	Cognitive scaffolding 1. Do you think what is personalized learning? 2. How to achieve personalized learning? 3. What kinds of learning methods can contribute to personalized learning? 4. How to make use of artificial intelligence to achieve personalized learning?
The scaffolding provided in the second round	Metacognitive scaffolding 1. Have you understood the collaborative learning task? What is the task standard and requirements? 2. What are the learning objectives of your group? How to achieve the learning objectives? 3. Have you made plans? How to assign roles, tasks, and manage time? 4. After the collaboration, please reflect and evaluate the whole collaborative learning process and group products. If there is any question, you can revise further to achieve the goal. Cognitive scaffolding 1. Do you think what is personalized learning? 2. How to achieve personalized learning? 3. What kinds of learning methods can contribute to personalized learning? 4. How to make use of artificial intelligence to achieve personalized learning?

(continued)

Table 4.3 (continued)

Rounds	The scaffolding
The scaffolding provided in the third round	Emotional scaffolding 1. Don't be sad when you have difficulties. Your group should be more positive and active to solve problems together 2. Don't be anxious. You can ask for help when you have difficulties. 3. Please discuss with your group members in a warm atmosphere of unity and friendship. Motivational scaffolding 1. This task is very valuable for getting a better understanding of personalized learning. You will benefit from it. 2. This task is very interesting and you can imagine what your future life will be like. 3. You are the best guys. Come on! Metacognitive scaffolding 1. Have you understood the collaborative learning task? What is the task standard and requirements? 2. What are the learning objectives of your group? How to achieve the learning objectives? 3. Have you made plans? How to assign roles, tasks, and manage time? 4. After the collaboration, please reflect and evaluate the whole collaborative learning process and group products. If there is any question, you can revise further to achieve the goal. 5. Please share your ideas actively. If you have any question, feel free to ask your peers. Cognitive scaffolding 1. Do you think what is personalized learning? 2. How to achieve personalized learning? 3. What kinds of learning methods can contribute to personalized learning? 4. How to make use of artificial intelligence to achieve personalized learning? 5. Please elaborate instructional design plan further to achieve personalized learning.

4.4 Results

4.4.1 Analysis of Collaborative Knowledge Building Level

This study analyzed the collaborative knowledge building levels of three rounds. Table 4.4 shows the results, including knowledge building, knowledge elaboration, and knowledge convergence of three rounds. It was found that the third rounds achieved the highest levels in term of knowledge building, knowledge elaboration, and knowledge convergence, followed by the second round. The first round achieved the lowest levels. The main reason lay in that the personalized scaffolding was provided for the third round collaborative learning based on the data of the first and second round collaborative learning. Figures 4.1, 4.2, and 4.3 are knowledge graphs generated in the three rounds.

Table 4.4 The results of collaborative knowledge build levels

Rounds	Groups	Knowledge building	Knowledge elaboration	Knowledge convergence
The first round	Group 1	226.31	331.53	103.93
The second round	Group 2	419.18	658.61	147.67
The third round	Group 3	730.24	1146.75	357.26

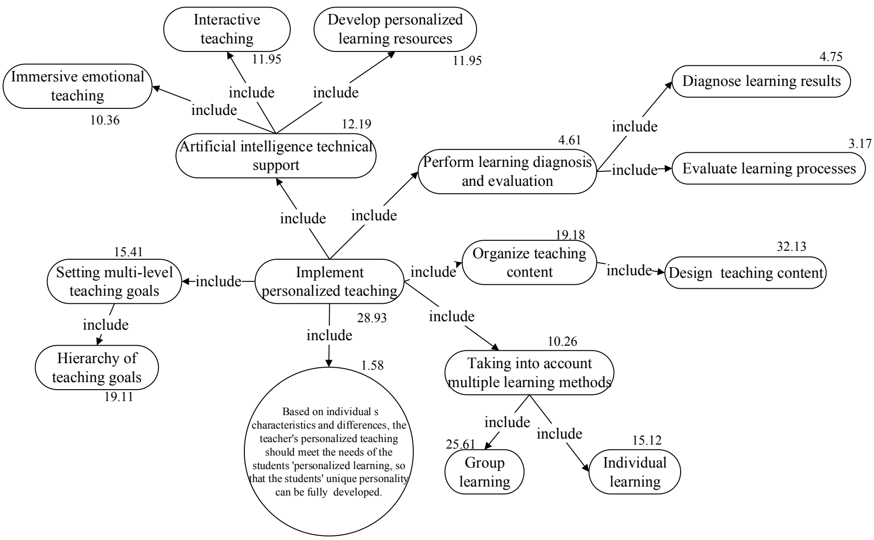

Fig. 4.1 The knowledge graph generated by group 1

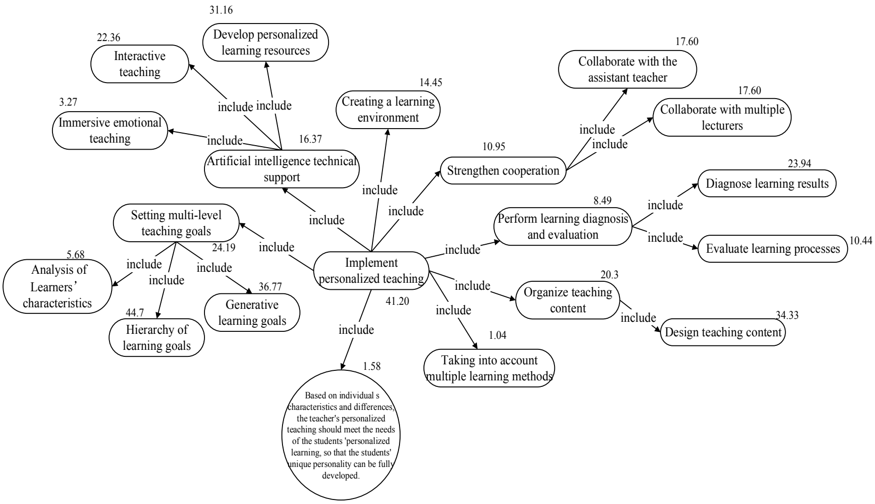

Fig. 4.2 The knowledge graph generated by group 2

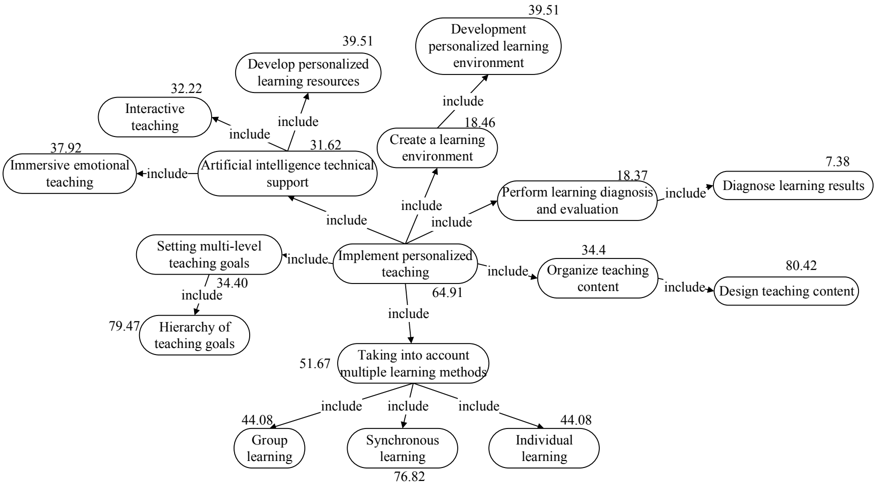

Fig. 4.3 The knowledge graph generated by group 3

4.4.2 Analysis of Group Products

This study also analyzed the group products quality of each group. The group products were instructional design plans. Table 4.5 shows the results of each round. It was found that group 3 achieved the highest score in group product quality, followed by group 2. Group 1 reached the lowest one. Group 3 designed the detailed instructional process to achieve personalized learning. More specifically, group 3 conducted instructional design based on learners' prior knowledge, cognitive style, and preference. While group 1 and group 2 did not take into account these factors and designed simple plans for learners.

Table 4.5 The results of group products

Rounds	Groups	Instructional objectives	Instructional emphasis	Instructional process	Total
The first round	Group 1	20	8	48	76
The second round	Group 2	18	8	57	83
The third round	Group 3	20	8	57	85

4.4.3 Interview Results

To get a better understanding of participants' perceptions about scaffolding, the semi-structured interview was conducted after collaborative learning. Overall, all of the participants believed that provided scaffolding was very helpful and useful. For example, one student said that "Initially, our group neglected collaborative learning objectives. After we read and think about the provided scaffolding, we found we did not achieve our goals. And then we revised the instructional design plan again. Finally, we completed the collaborative learning task and achieve our goals." Another student addressed that "The provided scaffolding was very useful for us because it provided the direction about how to achieve collaborative learning objectives and how to collaborate. The questions guided us to think about collaborative learning objectives, plans, strategies, monitoring, reflect and evaluate. I do like them."

4.5 Discussion and Conclusions

4.5.1 Discussion of Main Findings

This study adopted a data-driven approach to design and optimize scaffolding in CSCL. The scaffolding was revised and optimized three times based on analysis results of two rounds of collaborative learning. After the first round of collaborative learning, it was found that it was a lack of metacognitive scaffolding. Then metacognitive scaffolding was added in the second round of collaborative learning. After the second round of collaborative learning, it was found that learners also need to emotional and motivational support. Therefore, the emotional and motivational scaffolding was also added in the third round of collaborative learning. The findings indicated that collaborative knowledge building level and group products quality of the second round collaborative learning were improved than those of the first round.

The collaborative knowledge building level and group products quality of the third round of collaborative learning were improved further than those of the second round of collaborative learning. Hence, the optimization of scaffolding can indeed improve collaborative knowledge building level and group products quality.

4.5.2 Implications

The present study had several implications for teachers and practitioners. First, scaffolding needs to be designed elaborately ahead of collaborative learning. Learners need cognitive, metacognitive, and emotional scaffolding to support online collaborative learning. In addition, if learners are passive, motivational scaffolding is also necessary to motivate learners and facilitate collaborative learning.

Second, scaffolding included different types in different forms, such as guided questions, prompts, hints, useful tools, models, examples, and so on. Teachers and practitioners can select scaffolding based on learning objectives and learning contexts.

Third, scaffolding should be gradually faded when learners' abilities improved. Learners should be responsible for their learning and learn without scaffolding. Therefore, scaffolding can be faded when learners can solve problems by themselves. It should be noted that scaffolds should not be faded before learners acquired skills and novices might need a fuller set of scaffolds for a longer period (Tawfik et al., 2018).

Fourth, it was found that domain-general scaffolding was helpful for improving learners' transfer abilities (Bulu & Pedersen, 2010). Therefore, teachers and practitioners can provide more domain-general scaffolding other than domain-specific scaffolding to improve learners' transfer abilities.

Finally, it should be noted that scaffolding can increase learners' cognitive load. Too many scaffolding are not appropriate and it will increase learners' mental load. Therefore, teachers and practitioners should provide scaffolding when learners really need.

4.5.3 Limitations and Future Studies

The present study was constrained by several limitations. First, only one collaborative learning task was designed and implemented three rounds. Future study will design more collaborative learning tasks and implemented many rounds to summarize the principles of designing scaffolding. Second, this study only analyzed the collaborative knowledge building level and group products quality. Future study can analyze group metacognitive behaviors, emotions, and higher order skills. Finally, the current study did not examine the effects of scaffolding on learners' transfer abilities. Future study will examine learners' transfer abilities in other contexts.

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Part II
Case Studies on CSCL Activities

Chapter 5
Foster Learning Interest Based on the Interest-Driven Creation Theory in STEM Activities: A Case Study

Abstract Great learning interest contributes to success in various kinds of field. This case study aims to explore how to foster learning interest in STEM (Science, Mathematics, Engineering, and Technology) based on the interest-driven creation theory. The two STEM activities were designed and implemented according to the interest-driven creation theory. The first activity was to make a bookmark with a bridge, and the second was to make a bridge model. The learning interest questionnaire, group products, and interview results revealed that all of the participants were very interested in the two activities and STEM. The implications, limitations, and future studies are discussed in depth.

Keywords Learning interest · Interest-driven creation · STEM

5.1 Introduction

Mainstream education in China focuses extensively on examination for a long time (Hu & West, 2015; Tan, 2016). Therefore, students in China face higher examination pressure than students from Europe and the Americas. A pure examination focus has many negative effects. For example, examinations cause students to be more anxious and raise pressures to perform. Examinations also stifle students' creativity, imagination, and learning interests (Kirkpatrick & Zang, 2011).

Interest is a powerful motivational process that guides learning and career trajectories, and promoting interest contributes to success in career development (Harackiewicz et al., 2016). It was well-documented that there were many strategies for fostering learning interest. For example, designing meaningful learning tasks can trigger students' learning interest (Hidi & Renninger, 2006). Meaningful learning is conceptualized as the integration of new information with prior knowledge (Mayer, 2002). Meaningful learning activities should be closely related to participants' authentic lives (Schiefele, 2009) and interesting tasks (Murayama et al., 2013). In addition, Hidi and Renninger (2006) suggested that triggering and maintaining interest can be achieved through generating curiosity questions, adopting appropriate learning methods, and developing efficient learning environments. However, there

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is a lack of study on fostering learning interest based on the interest-driven creation theory. This study aims to fostering learning interest through the interest-driven creation theory in the STEM field.

It should be noted that there are some differences among interest-driven creator theory, social constructivism theory, and distributed constructivism theory. The interest-driven creator theory focuses on nurturing learners' creativity through developing interest and formation of creative habit (Chan et al., 2018). Social constructivism theory emphasizes that construction of knowledge is the product of social interaction, and a socio-cultural context plays an important role in learning (Adams, 2006; Atwater, 1996). Distributed constructivism focuses on collaborative activities for developing a knowledge-building community (Resnick, 1996).

5.2 Literature Review

5.2.1 The Research on STEM

STEM (science, mathematics, engineering, and technology) field can be dated back to the 1990s when the US NSF formally included engineering, technology, science, and mathematics in K-12 and higher education (Li et al., 2020). STEM literature include awareness of the roles of STEM, familiarity with the fundamental concepts, having a basic application fluency (NAE and NRC, 2014; Margot & Kettler, 2019). Li et al. (2020) conducted a literature review about research trends of STEM and found that STEM education is increasingly important in the world as well as more and more journals published papers about STEM.

How to implement STEM is a major concern in the field of education. Park et al. (2018) believed that designing STEM activity was very important because these activities provided the opportunity to solve complex and cross-disciplinary problems. Thibaut et al. (2018) believed that there were five instructional methods in STEM practice, including integration of STEM content, problem-centered learning, inquiry-based learning, design-based learning, and cooperative learning. In addition, Chittum et al. (2017) conducted two after-school Studio STEM programs, and they found that students were motivated in two STEM programs and the experience had a positive impact on their perceptions about science. Karahan et al. (2015) found that STEM-integrated media design processes positively impacted the 8th grade students' attitudes toward science. Walan (2019) integrated makerspace activities and drama, and they found that students developed an interest in STEM as well as twenty-first-century skills.

Kuo et al. (2019) proposed a STEM interdisciplinary project-based learning (IPBL) approach to develop a human–computer interaction (HCI) system, and they found that participants' learning motivation and creativity were improved. However, only few studies paid attention to how to design learning activities to foster students' learning interest based on the interest-driven creation theory in the STEM field. This study aims to close the gap and focus on fostering learning interest in STEM based on the interest-driven creation theory.

5.2.2 Learning Interest

Interest is conceptualized as the psychological state of engaging in particular classes of objects, events, or ideas over time (Hidi & Renninger, 2006). There are two types of interests, including situational interest and individual interest (Hidi & Renninger, 2006; Hong et al., 2019). The situational interest is defined as the focused attention and affective reaction triggered by environmental stimuli (Hidi, 1990; Hidi & Renninger, 2006). The individual interest is defined as a person's relatively enduring predisposition to reengage a particular class of objects, events, or ideas (Hidi & Renninger, 2006; Renninger, 2000).

Furthermore, Hidi and Renninger (2006) developed a four-phase interest model, which included triggered situational interest, maintained situational interest, emerging individual interest, and well-developed individual interest. These four phases contribute to fostering interest from situational interest to stable individual interest. In addition, Hong et al. (2019) found that triggered situational interest was positively associated with maintained situational interest that was positively associated with emerging individual interest. Emerging individual interest was positively associated with well-developed individual interest (Hong et al., 2019).

It has been well-documented that there are many strategies for fostering learning interest. For example, developing interdisciplinary courses may help increase learning interest (Lai, 2018). Arousing curiosity was another effective strategy to trigger learning interest (Rotgans & Schmidt, 2014; Wong et al., 2020). Experiencing the flow in the activity can contribute to immersing interest (Wong et al., 2020). Heddy et al. (2017) found that meaningful learning can facilitate the development of interest for at-risk college students. In addition, some researchers adopted information technologies to foster learning interest. For example, Hochberg et al. (2018) adopted smartphone to enhance learning interest in learning science. Hwang and Chang (2016) found that the peer competition-based mobile learning approach had a significant impact on learning interest.

5.2.3 Interest-Driven Creation Theory

Chan et al. (2018) first proposed the interest-driven creator (IDC) theory that aims to nurture learners' creativity and form the habit of creation through fostering interest. There are three loops included in the IDC theory, namely, the interest loop, the creation loop, and the habit loop (Chan et al., 2018). Wong et al. (2015) proposed that the interest loop involves triggering interest, immersing interest, and extending interest. Furthermore, Wong et al. (2020) proposed the design strategies of triggering, immersing, and extending interest, including curiosity-driven learning, flow experience, and meaningful learning. The creation loop includes three phases, namely, imitating, combining, and staging (Chan et al., 2018). Chan et al. (2019) believed that imitating focuses on knowledge absorption; combining is concerned with knowledge generation; and staging relates to elevation and social recognition. The habit loop includes cuing the environment, routine, and harmony (Chan et al., 2018). Chen et al. (2020) believed that cuing the environment can trigger a habit, and routine is the repeated behavioral pattern, which leads to be satisfied and experience inner peace for the stabilization of habits.

The interest-driven creation theory has been applied to design curriculum and learning activities. For example, Kong and Li (2016) used the interest-driven creator theory to design K-12 programming course and put IDC theory into coding education practice. Liu et al. (2016) applied the interest-driven creator theory to develop learners' computational thinking and get a better understanding of the abstract concepts in mathematics in higher education. Huang et al. (2020) applied the interest-driven creator theory to design an interest-driven video creation activity. They found that students' mathematics achievements significantly improved, and they all had low anxiety and positive attitude after they participated in the interest-driven video creation activity. However, there is a lack of using the interest-driven creator theory in STEM activities. This study aims to put the interest-driven creator theory into STEM practice to foster students' learning interest. The following sections will describe the methods, results, implications, and conclusions.

5.3 Method

5.3.1 Participants

This study enrolled eight pupils to participate in two STEM activities. There were two girls and six boys. The average age was 9 years. They have learned science in primary school. They were randomly divided into three groups with two or three students. They had not collaborated before. They voluntarily participated in this study after getting the consent of their parents.

5.3.2 STEM Activity Design

This study designed two STEM activities to foster students' learning interests. The first activity was to make an innovative bookmark with a bridge. The second activity was to build an innovative bridge model with group members. Table 5.1 shows the design plan of the first activity, and Table 5.2 shows the design plan of the second activity.

Table 5.1 The design plan of the first activity

Dimensions	Explanations
Learning objectives	Know about the four famous bridges in China and the structure of a bridge. Learn how to build a bridge.
Learning task	Make a bookmark with a bridge through heat-shrinkable sheets.
Learning materials	Lecture notes, task sheets, heat-shrinkable sheets, heat guns, color leads, acrylic plates, rubbers, scissors, tweezers, and lifting ropes
Learning processes	1. Phase 1: Imitating • Trigger interest: demonstrated the four famous bridges in ancient Chinese architecture. • Immerse interest: introduced the four famous bridges (Zhaozhou bridge, Luoyang bridge, Lugou bridge, and Luding bridge) in terms of history, structure, and characteristics. • Extend interest: introduced the important value, types, aesthetics of bridges. 2. Phase 2: Combining • Trigger interest: introduced the ancient poetry that describes the bridges. • Immerse interest: students selected one ancient poetry to draw a picture about this ancient poetry. • Extend interest: each group made a bookmark with a bridge using the provided materials. 3. Phase 3: Staging • Trigger interest: each group prepared to demonstrate the built bridge. • Immerse interest: each group presented the built bridge to all participants. • Extend interest: students evaluated the other groups' bridge and the teacher summarized the whole learning activity.

5.3.3 Procedures

At the beginning of this study, the teacher introduced the research purpose, processes, and requirements to all participants. And then all participants were randomly divided into three groups. Each group member conducted self-introduction and team building warm-up exercises. The three groups conducted two STEM learning activities step by step. The whole learning process was recorded to analyze how to complete group products. By the end of the learning activity, the post-test questionnaire of learning interest was distributed to all participants. The 5-point Likert learning interest questionnaire was adapted from Hong et al. (2019), and it consisted of 16 items. Finally, a semi-structured interview was conducted to understand the perceptions of participants.

Table 5.2 The design plan of the second activity

Dimensions	Explanations
Learning objectives	• Know about the structure, types, and aesthetics of bridges. • Understanding the relationships between the types and weight capacity of bridges. • Learn how to build a bridge model and enjoy the process.
Learning task	Build an innovative bridge model with group members.
Learning materials	Lecture notes, task sheets, glue guns, hardboards, wide sticks, and scissors
Learning processes	1. Phase 1: Imitating • Trigger interest: introduced different types of bridges in the world, such as beam bridges, truss bridges, arch bridges, tied arch bridges, cantilever bridges, suspension bridges, and cable-stayed bridges. • Immerse interest: discussed the relationships between the types and weight capacity of bridges; shared a video about the Hong Kong–Zhuhai–Macau Bridge. • Extend interest: introduced the negative case: why the Tacoma Narrows Bridge fell. 2. Phase 2: Combining • Trigger interest: each group designed a bridge according to load and resistance factor design principles. • Immerse interest: each group built a bridge model with beautiful appearance, strong deck, strong weight and traffic loading, and reasonable proportion. • Extend interest: each group revised the bridge model based on teacher's suggestions. 3. Phase 3: Staging • Trigger interest: each group demonstrated the built bridge model. • Immerse interest: students evaluated the bridge models of other groups and think about the relationships between the types and weight capacity of bridges. • Extend interest: the teacher shared the videos about bridges, summarized the whole learning activity, and encouraged students to build a bridge for our country.
Assessment methods	The group products were evaluated by teachers based on the criteria.

5.4 Results and Discussion

5.4.1 Analysis of Learning Interest

Table 5.3 shows the results of learning interest. Learning interest include situational interest and individual interest (Hong et al., 2019). There were four dimensions for the questionnaire, including triggered situational interest, maintained situational interest, emerging individual interest, and well-developed individual interest (Hong et al., 2019). The reliability of the questionnaire achieved 0.81. The results indicated that most students were very interested in building a bridge model. The mean values of triggered situational interest, maintained situational interest, emerging individual interest, and well-developed individual interest were 4.54, 4.55, 4.94, and 4.78, respectively. Furthermore, the mean value of individual interest was larger than the situational interest. This finding indicated that the two activities based on the interest-driven creation theory can foster students' situational interest and individual interest.

Table 5.3 The results of learning interest questionnaire

Items	*M*	*SD*
Triggered situational interest	4.54	0.57
1. I found it very interesting when I made a bridge model.	4.75	0.46
2. I found that the function of the bridge model was very fascinating.	4.75	0.46
3. I enjoyed designing different types of bridge model.	4.13	1.46
Maintained situational interest	4.55	0.30
4. I believe that it is very exciting to find the connection between making models and scientific concepts when I have made several bridge models.	4.75	0.71
5. I find myself enjoying finding out the reasons for the problems even when I have made several bridge models.	4.38	1.41
6. I still reflect on the built bridge model even when I have made several bridge models.	4.75	0.71
7. I still want to improve the built model from a scientific viewpoint even when I have made several bridge models.	4.63	0.74
8. I still find a strong link among engineering design, mathematics, and science even when I have made several bridge models.	4.25	0.89
Emerging individual interest	4.94	0.20
9. As long as there is a bridge model contest, I would be interested in making models and I do not care whether I win the contest or not.	5.00	0.00
10. I find myself dwelling more on making bridge models than doing other schoolwork.	5.00	0.00
11. I am very excited after I built a bridge model.	4.88	0.35
12. I find that time passes very quickly when I make a bridge model.	4.88	0.35
Well-developed individual interest	4.78	0.08
13. I found myself learning more problem-solving strategies from making a bridge model than from doing other schoolwork.	4.88	0.35
14. I think it is more meaningful to learn about science through making a bridge model.	4.63	0.52
15. I find that I can develop thinking strategies by making a bridge model.	4.75	0.46
16. I find that I can apply similar problem-solving strategies in other activities after I make a bridge model.	4.88	0.35

5.4.2 Analysis of Group Products

This study engaged three groups in building a bridge model. Figures 5.1, 5.2, and 5.3 are the models built by these three groups. The teacher and students evaluated the built models based on the assessment criteria, as shown in Table 5.4. The results indicated that the third group achieved the highest score (95), followed by the first group (89) and the second group (78). The main reason was that the bridge model built by the third group was more stable, strong, and innovative than the other two groups.

Table 5.4 The assessment criteria for group products

Dimensions	Descriptions	Score
Structure	The group product is well designed and constructed.	20
Functionality	The group product works well and as intended.	25
Originality	The group product design incorporates innovative ideas and unique feature.	30
Quality	The group product is high quality in terms of its shape, structure, and functionalities.	25

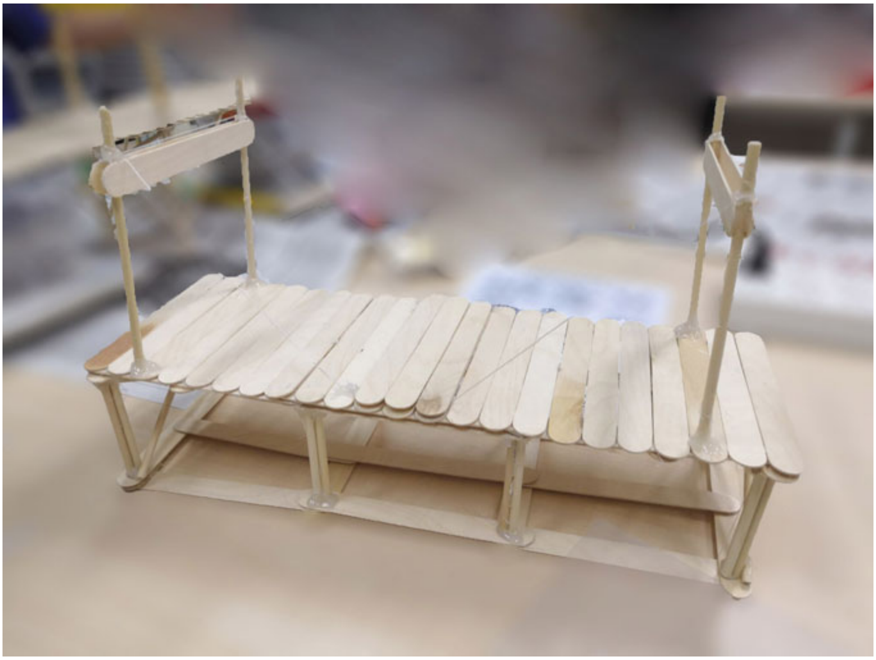

Fig. 5.1 The bridge model of the first group

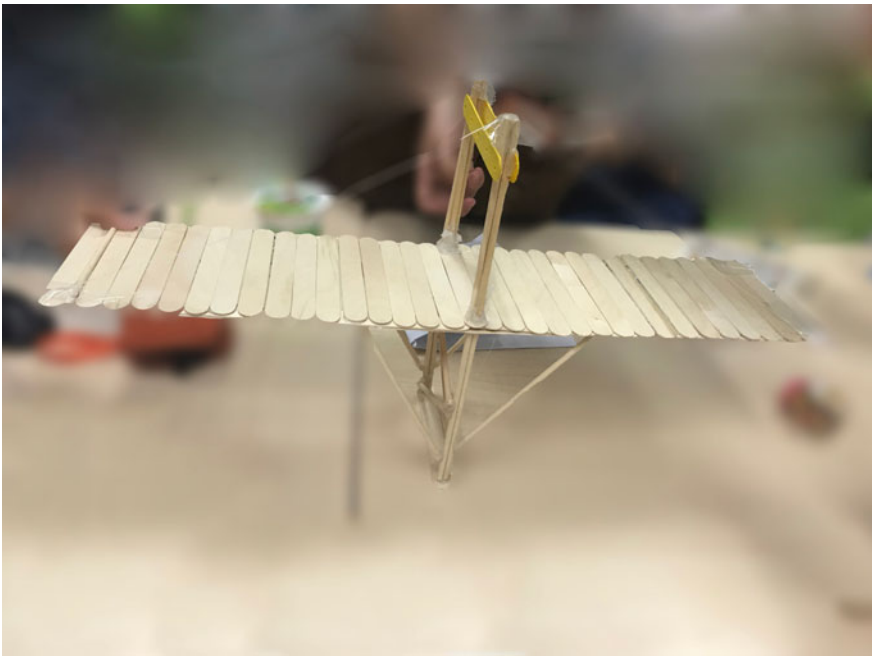

Fig. 5.2 The bridge model of the second group

5.4.3 Interview Results

After the activity, a semi-structured interview was conducted to get a better understanding of participants' perceptions. First, all participants expressed that they all enjoyed the two activities. As one student stated "I like this activity very much. Usually, I learn science by self-directed learning. But now I can collaborate with group members to build a bridge model together. I am very interested in this activity. I hope I will be an engineer when I grow up".

Second, all of the interviewees believed that the two activities can help to foster their interest. The teacher triggered interest, immersed interest, and extended interest through different methods. As one student said that "Initially, I don't like build a model. But when I collaborate with our group members I learned a lot from them. This makes me to contribute more when we build the bridge model. Now I am very interested in building a bridge model and I still find that we can build a better bridge model later."

Third, most interviewees believed that building a bridge model was helpful in improving their imagination and creativity. As one student addressed "Our group members believed that we can build a very strong and long bridge that can hold many cars. Then we designed an innovative model to achieve this goal. To reduce

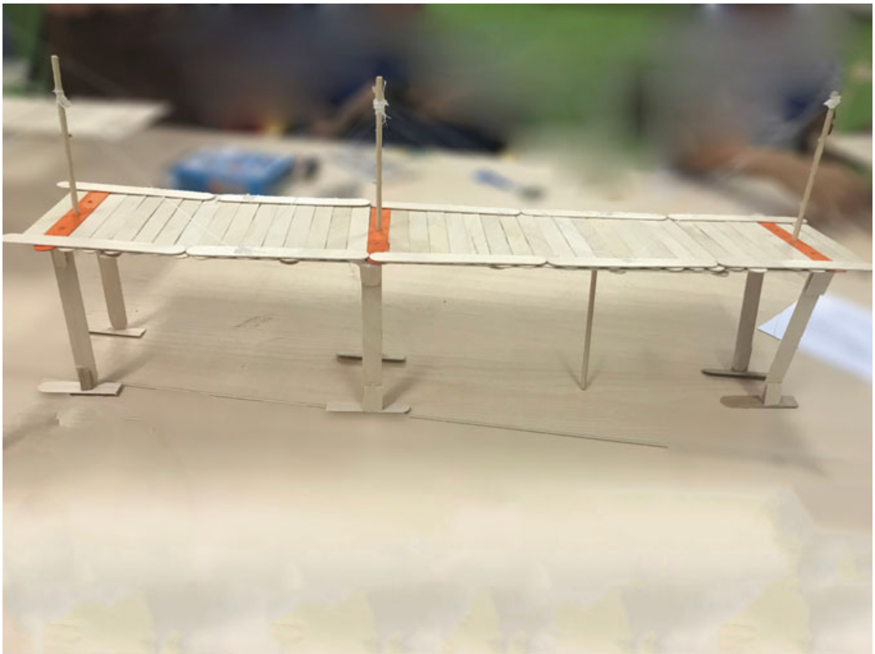

Fig. 5.3 The bridge model of the third group

the weight of the bridge, we designed many ropes to reduce the weight of the bridge and traffic load."

5.4.4 Implications

This study has several implications for teachers and practitioners. First, it was found that the interest-driven creator theory was helpful for fostering students' learning interests. The interest loop includes triggering interest, immersing interest, and extending interest according to the interest-driven creator theory (Chan et al., 2018). Therefore, teachers and practitioners should design appropriate learning activities to trigger interest, immerse interest, and extend interest.

Second, in terms of triggering interest, it was found that curiosity-driven learning was useful to trigger interest (Wong et al., 2020). In addition, the innovative learning environment can also trigger learning interest (Hidi & Renninger, 2006). Furthermore, Sun et al. (2018) found that scaffolding, collaboration, and perceived ease of using digital learning environment were very helpful for triggering interest. Problem-based learning was also another effective strategy for triggering learning interest (Liu et al., 2019). Therefore, curiosity-driven learning, the innovative learning environment, scaffolding, and problem-based learning can be integrated into the interest-driven creator theory to stimulate learning interest.

Third, immersing interest can be achieved through experiencing of flow (Wong et al., 2020). That is to say, learners are in a concentration state when they engage in a particular learning activity. In addition, learners' interest can be immersed through visiting a particular palace such as science museum (Brown Jarreau et al., 2019).

Fourth, extending interest can be achieved through meaningful learning (Wong et al., 2020). Meaningful learning enhanced utility value, which leads to increased learning interest (Harackiewicz et al., 2016). In addition, sharing, demonstration, performance, and receiving feedback as well as recognition are also useful for extending interest. Extending interest contributes to transforming situational interest into individual interest.

Fifth, it should be noted that there are differences in implementing learning activities between a school and a museum. For example, learning activities in a school are structured and organized, while activities in the museum are flexible (Shaby & Vedder-Weiss, 2020). It is also the lack of interactive exhibition at school. Furthermore, it is found that interactive exhibitions in a science museum contributed to increasing visitors' engagement (Shaby et al., 2017), holding attention (Sandifer, 2003), and enriching hands-on multifaceted learning experience (Shaby et al., 2019). Therefore, teachers and practitioners can integrate interactive exhibitions in a science museum into an IDC approach to implement learning activities.

5.5 Conclusions

This study conducted a case study and designed two STEM activities to foster pupils' learning interest according to the interest-driven creator (IDC) theory. The topic of the case study was about the bridge: one focused on making a bookmark with bridge, another centered on making a bridge model. The results of questionnaire, group products, and interview indicated that all the participants were very interested in the two activities. Guided by the IDC theory, students' learning interests were triggered, immersed, and extended step by step.

However, there are several limitations to this study. First, the case study was conducted only to explore how to foster learning interest. Future study will conduct an empirical study to examine fostering learning interest through the application of IDC theory. Second, learners' interest in this study was situational interest and had not transformed into individual interest. Future study will focus on how to foster individual interest through longitudinal study over a long time. Third, this study only focused on fostering learning based on IDC theory. In the future study, it will be very interesting to investigate how to form the habit of creation.

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Chapter 6
Improving Programming Skills Through an Innovative Collaborative Programming Model: A Case Study

Abstract In recent years, education has put considerable emphasis on the development of programming skills. However, students, especially, pupils often face challenges in programming. This study aims to improve pupils' programming skills through an innovative collaborative programming model. This model includes six phases, namely, understanding, designing, programming, sharing, evaluating, and refining. A case study was conducted to get a better understanding of participants' perceptions, programming skills, and collaborative problem-solving abilities. The results indicated that participants were interested in programming, and their programming skills as well as problem-solving abilities were improved. The implications for teachers and practitioners are also discussed in depth.

Keywords Collaborative programming · Collaborative problem solving · Programming skills

6.1 Introduction

The development of advanced technologies requires lots of human resources in programming skills (Lu et al., 2017). Computer science education has become more and more important in recent years (Chen et al., 2017). Thus, computer programming course has been a very fundamental course at all levels (Gordon & Brayshaw, 2008). Vaca-Ca´rdenas et al. (2015) proposed that programming skills are very crucial for preparing students for twenty-first-century success. Therefore, there is an urgent need to improve learners' programming skills.

Previous studies reported many strategies for improving computer programming skills, such as the use of robot (Noh & Lee, 2020), problem posing-based strategy (Wang & Hwang, 2017), developing a groupware system (Bravo et al., 2013), and flipped classroom model (Durak, 2020). However, the effectiveness of these strategies for pupils need to be investigated further. In addition, novice programmers like pupils encountered a number of problems and challenges. It was found that the first programming experience affected the interest and willingness of programming (Uysal, 2014). Therefore, it is necessary to develop a holistic model to help novice

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programmers to improve their programming skills. This study sought to propose an innovative model to help pupils to improve collaborative programming skills in an Arduino course. The present study also validated the feasibility of the proposed model through a case study. Arduino provided an introduction to microcontrollers, and the graphical languages made it accessible to non-programmers (Reas & Fry, 2014). The following sections will illustrate literature review, method, results, and conclusions.

6.2 Literature Review

Collaborative programming has been considered as a very effective strategy for improving programming skills (Bailey & Mentz, 2017). Kanika et al. (2020) found that collaborative programming enabled students to learn from peers and write efficient programs. Teague and Roe (2008) believed that collaborative programming was very helpful for novice programmers in terms of establishing collective understanding of problems, receiving peers' feedback, and building knowledge. Many scholars investigated on how to improving programming skills through collaborative programming. For example, Lu et al. (2017) applied learning analytics to improve programming skills in a MOOCs collaborative programming course. Chorfi et al. (2020) adopted a computer-supported collaborative learning-based groupware to improve programming skills. Lu et al. (2020) proposed that a continuous inspection paradigm can serve as an effective method to ensure coding quality and improve programming skills. Wei et al. (2020) proposed a partial pair programming method, and they found that elementary school students' computational thinking skills and self-efficacy improved through the partial pair programming method.

In addition, it was found that computer programming is a problem-solving task (Piteira & Costa, 2013), and programming skills are closed related to problem-solving skills (Fessakis et al. 2013). Previous studies also indicated that problem-solving is a crucial aspect of programming (Deek et al., 1999; Shi et al., 2019). Beck and Chizhik (2013) proposed that collaborative programming helped learners to develop confidence in problem-solving abilities. Sun et al. (2020) analyzed three contrasting pairs' collaborative programming processes, and they demonstrated the complex relations among collaborative behaviors, discourses, and performances. However, most studies implemented collaborative programming in higher education context. Few studies conducted collaborative programming among elementary school students. To close this gap, this study aims to improve pupils' programming skills through the proposed model. The following sections will illustrate the proposed model in depth.

6.3 The Model of Collaborative Programming

This study proposed an innovative model of collaborative programming, including understanding, designing, programming, sharing, evaluating, and refining. This model aims to improve learners' collaborative problem-solving skills and programming skills, as shown in Fig. 6.1. It is a cycle, and there are six phases. The first phase is to understand the context, task requirements, and learning objectives of programming. The second phase is to design how to program and draw the flowchart to represent the thoughts. The third phase is to program collaboratively through online programming tools. In this phase, learners need to program and debug the code. The fourth phase is to share the group products with peers and teachers. The fifth phase is to evaluate the quality of group products by teachers and peers. The final phase is to refine and revise the program further based on teachers' and peers' suggestions.

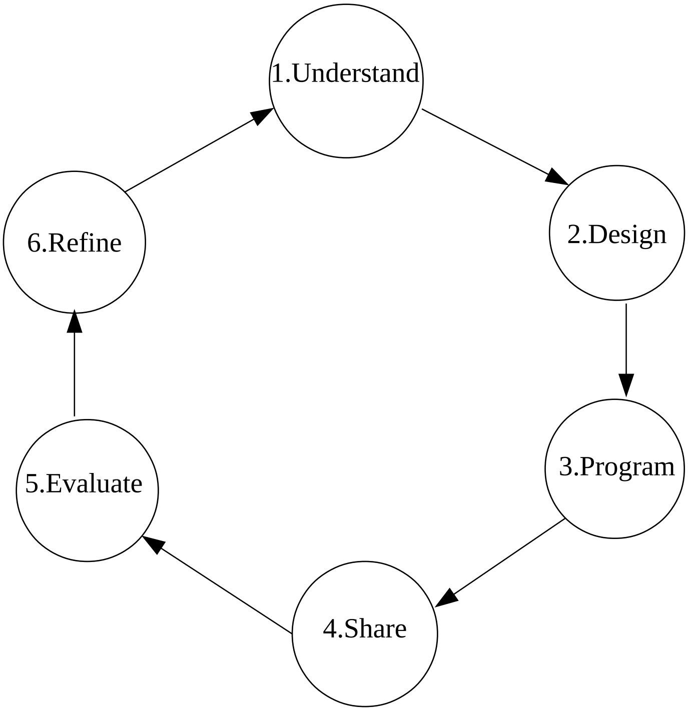

Fig. 6.1 The model of collaborative programming

6.4 Method

6.4.1 Participants

This study enrolled 9 pupils to voluntarily participate in this study. All the participants were divided into 4 groups of two or three students. Groups 1 and 3 were composed of girls. Groups 2 and 4 were composed of boys. The average age was 11 years. They were from the same elementary school. However, they had never collaboratively programmed before. They did not know how to program.

6.4.2 The Introduction to the Program

The tasks of the program were to make a fortune cat through a steering engine. The learning objectives of this program were to understand the principles and control method of a steering engine as well as acquire the applications of random number and key module. After participation in this study, students' interest in programming and programming skills was expected to be enhanced further. The learning materials include lecture notes, Arduino tools, the examples of programming, computers, scissors, gummed tape, colored paper, and colored pencil.

6.4.3 Procedures

This study followed the proposed collaborative programming model to design and implement the collaborative programming activities. Table 6.1 shows the procedures of the learning activity.

6.5 Results

6.5.1 Analysis of Programming Skills

Since each group collaboratively programmed and programming was the final group product, the rubric was designed to evaluate the programming skills. Table 6.2 shows the rubric of group products, and Table 6.3 shows the assessment results. It was found that group 4 achieved the highest score, followed by group 3, group 2, and group 1. Compared with previous programming skills, all the participants' programming skills were significantly improved (Fig. 6.2).

Table 6.1 The procedure of the first learning activity

Phases	Teachers' behaviors	Students' behaviors
1. Understand	1. The teacher demonstrated the pictures of various kinds of cats and asked a question "Do you know about the fortune cat?" 2. The teacher asked, "What are the major differences in these fortune cats?" 3. The teacher introduced the task and demonstrated the functionalities of made fortune cat. The principles and control methods of a steering engine as well as how to draw flowchart were also introduced by the teacher.	1. The students answered the question and linked it with their prior knowledge and experience. 2. The group members searched for information from the Internet and answered the question. 3. The students observed the made fortune cat, understood the task, and learned about the target knowledge.
2. Design	1. The teacher engaged students in designing the appearance of the fortune cat. 2. The teacher engaged students in designing the flowchart of the program.	1. The group members conducted collaborative learning to draw the fortune cat together. 2. The group members conducted collaborative learning to draw the flowchart of the program together.
3. Program	The teacher introduced how to program through the MIXLY (an open-source software) and the hardware.	1. The group members collaboratively program to make a fortune cat that can swing the arms. 2. Once they finished, they connected the hardware to test.
4. Share	The teacher organized the students to share their group products and discuss among all participants.	Each group shared their group products and discussed with peers.
5. Evaluate	The teacher evaluated the group product of each group.	Each group reflected and thought on how to improve the group products.
6. Refine	The teacher summarized and provided their suggestions to refine the group products.	Each group refined the group products further and demonstrated the revised group products.

Table 6.2 The rubric of group products

Dimensions	Explanations (10)	Explanations (15)	Explanations (20)
Originality (20)	The group product is not original and just followed the teachers' model.	The group product is a little bit innovative.	The group product is very original and innovative.
Programming (20)	The flowchart is incomplete, and there are some errors in programming.	The flowchart is complete and there is no error in programming.	The flowchart is perfect and the programming works well.
Hands-on skills (20)	The hands-on skills are low and the connection of hardware is loose and in chaos.	The hands-on skills are medium, and the connection of hardware is in order.	The hands-on skills are high, and the connection of hardware is firm and perfect.
Collaboration (20)	There is no communication and collaboration.	There is little bit communication and collaboration.	The group members communicated and collaborated closely.
Functionality (20)	The group product did not achieve the expected functionalities.	The group product achieved the expected functionalities.	The group product achieved the expected functionalities, and several new functionalities were added.

Table 6.3 The results of group products

Groups	Originality	Programming skills	Hands-on skills	Collaboration	Functionality	Total
Group 1	18	10	14	12	15	69
Group 2	15	18	16	13	15	77
Group 3	17	16	16	14	15	78
Group 4	17	18	18	17	15	85

6.5.2 *Analysis of Collaborative Problem Solving*

This study adopted the collaborative problem-solving framework developed by PISA (2017) to evaluate collaborative problem-solving competency. This assessment framework is a matrix which is composed of vertical components and horizontal components. The vertical components were coded as (A) explore and understand (20 scores), (B) represent and formulate (25 scores), (C) plan and execute (30 scores), and (D) monitor and reflect (25 scores) (PISA, 2017; Song, 2018). The horizontal components were coded as (1) establish and maintain shared understanding (45 scores), (2) take appropriate action to solve the problem (25 scores), and (3) establish and maintain team organization (30 scores) (PISA, 2017; Song, 2018). The result of the collaborative problem-solving competency was the matrix of ABCD1, ABCD2, and ABCD3. Table 6.4 shows the results of collaborative problem solving for four groups. It was found that group 4 achieved the highest score in collaborative problem-solving competency, followed by group 3, group 2, and group 1.

Fig. 6.2 The programming of group 4

Table 6.4 The results of collaborative problem solving

Groups	Matrix1	Matrix2	Matrix3	Total
Group 1	31	12	20	63
Group 2	33	18	22	73
Group 3	35	20	25	80
Group 4	39	23	27	89

6.5.3 Interview Results

To get a better understanding of the participants' perceptions, all the participants were interviewed by researchers. The interview results indicated that participants were more interested in programming, and their programming skills as well as collaborative problem-solving skills were improved further.

First, the participants of the four groups addressed that this activity was very interesting, and their interests in programming increased. For example, one student said that "Before I believed that programming is very difficult. But now I believe that programming is very interesting and not difficult because I can program through the graph programming tool. The text programming tool is very boring." Another student also addressed that "I like this activity very much. I benefit a lot from it. I have a strong sense of fulfilment when I finish program. I feel very exciting when the fortune cat can swing the arms."

Second, the participants of four groups believed that the proposed model can improve their programming skills. For example, one student stated that "Before, I just programming directly without design. I never revise the program before. But now I learn how to programming in a proper way. I understand the task and requirements of program, then I begin to design the flow chart. And then our group program and share with peers." Another student also revealed that "Understanding, design, programming, sharing, evaluation, and refinement are very scientific and useful for improving programming skills. I learn a lot from this model."

Third, the participants of the four groups believed that the proposed model improved their collaborative problem-solving skills. As one student said "Initially, there are some grammar errors in programming. Later our group members collaboratively corrected the errors and tested again. Finally, the fortune cat's arms swing." Another student revealed that "I believe the evaluating and refining group products is very important for improving problem solving skills. I learn a lot from refinement and solve several problems."

6.5.4 Implications

This study had several implications for teachers and practitioners. First, the proposed collaborative programming model was very effective and useful for improving programming skills. This model includes six phases, namely, understanding, designing, programming, sharing, evaluating, and refining. These six phases were an iterative cycle with the aim of improving programming skills. Among these six phases, programming and refining programming are very important. In addition, debugging is a fundamental skill of programming (Beller et al., 2018), and novice programmers took significantly more time in debugging (Chiu & Huang, 2015). Therefore, teachers and practitioners should allocate enough time to debug for programmers.

Second, novice programmers need help from teachers or experts. Therefore, it is suggested that teachers guide novice programmers to follow the model to improve programming skills step by step. In addition, novice programmers may encounter various kinds of problems. Teachers should provide real-time feedback for novice programmers, including emotional and cognitive feedback. For example, Fwa (2018) developed an affective tutoring system to help novice programmers to regulate their negative affect.

Third, learning activities about programming need to be elaborately designed before implementation since programming is considered to be a creative activity (Grover & Pea, 2013). The programming tasks, requirements, questions, interactive strategies, programming environments, learning materials, and assessment methods need to be designed carefully. It was found that visual presentation (diagrams, video, animation) and verbal explanation contributed to learning programming (Zhang et al., 2014). The drag and drop type applications can help younger students to learn computer science and informatics concepts (Kalelioğlu, 2015). Therefore, appropriate and smart programming environments are very crucial for improving programming skills.

6.6 Conclusions

This study investigated how to improve programming skills through an innovative collaborative programming model. This model included six steps, namely, understanding, designing, programming, sharing, evaluating, and refining. A case study was conducted to examine the feasibility and effectiveness of this model. The results indicated that the proposed model was very helpful and insightful for improving programming skills. The best group achieved the highest scores in terms of group product's quality and collaborative problem-solving skills. The interview results revealed that all the participants were very interested in programming, and their programming skills as well as collaborative problem-solving skills improved further.

However, this study was constrained by several limitations. First, only four groups participated in this study. Therefore, cautions should be exercised when generalizing the results. Future study will expand the sample size to conduct the empirical study. Second, this study only examined the group product quality and collaborative problem-solving abilities. Future study will examine the effectiveness of the proposed model from other perspectives.

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Chapter 7
Facilitating Cross-Cultural Collaborative Learning Through Collaboration Scripts: A Case Study

Abstract Cross-cultural collaboration is important for twenty-first century success. This study focused on how group members co-constructed knowledge and completed group products with the aid of scripts in a cross-cultural collaborative learning context. Three groups participated in this study and they completed the same task using the same scripts. The discussion transcripts of three groups were analyzed in depth to understand the role of scripts. The results indicated that the collaboration of scripts were useful and helpful for facilitating cross-cultural collaborative learning. The collaborative knowledge-building level differed due to the individual differences. The findings together with implications for implementing cross-cultural collaborative learning are discussed in depth.

Keywords Cross-cultural collaborative learning · Knowledge building · Scripts

7.1 Introduction

In recent years, more and more people are aware of the importance of understanding the culture of others in a global society (Shadiev & Huang, 2016). The cross-cultural communication is very helpful for maintaining relations (Bartell, 2003), understanding other culture, and interacting comfortably (Huang et al., 2015). However, previous studies revealed that students had difficulties in cross-cultural collaboration. Wang (2011) believed that the main challenge for cross-cultural collaboration was the language barrier. Cagiltay et al. (2015) found that communication, media, and conflict were barriers to cross-cultural collaboration.

To overcome these challenges, it is necessary to provide extra support to facilitate cross-cultural collaboration. It was found that scripts were helpful for cross-cultural collaboration (Popov et al., 2013). Scripts are external support for collaborative learning provided by a teacher to engage learners in interaction (Kollar et al., 2006). Weinberger et al. (2007) believed that external scripts provided a feasible approach to facilitate the engagement of diverse culture learners. Computer-supported collaborative learning scripts are considered as scaffolding for the social interactions necessary for collaborative learning (Kollar et al., 2006).

L. Zheng, *Data-Driven Design for Computer-Supported Collaborative Learning*, Lecture Notes in Educational Technology,
https://doi.org/10.1007/978-981-16-1718-8_7

However, little known is that how to promote collaborative knowledge building through scripts in a cross-cultural collaborative learning context. The present study focused on facilitating collaborative knowledge building through scripts during cross-cultural collaboration. The rest of this chapter is organized in the order of literature review, method, results, and conclusion.

7.2 Literature Review

7.2.1 Cross-Cultural Collaborative Learning

Culture is conceptualized as the customs, language, and knowledge a group of people shares (Kittler et al., 2011). It was found that culture had an impact on shaping perceptions, communication, collaboration, and behaviors (Popov et al., 2013; Shi et al., 2013). Same-culture groups hold the same behavioral norms, perceptions, and communication styles (Lim & Liu, 2006; Popov et al., 2013). To promote the communications of different culture, cross-cultural collaboration plays an important role. Chen et al. (2012) found that cross-cultural online collaborative learning facilitated dynamic and reciprocal communication and interaction, which promoted positive learning outcomes further. It has been reported that online cross-cultural collaborative learning significantly improved participants' English ability (Jeon & Lim, 2013; Schulz, 2007).

However, cross-cultural groups often hold different views and suffer from misunderstanding and conflicts (Weinberger et al., 2007; Popov et al., 2013). To facilitate cross-cultural collaborative learning, many strategies have been adopted to decrease misunderstanding and conflicts. For example, Shadiev and Huang (2016) adopted speech-to-text recognition and computer-aided translation systems to support cross-cultural communication and collaboration. Kumi-Yeboah (2018) proposed that self-introduction, the inclusion of global examples, and cultural awareness activity were necessary for cross-cultural online collaborative learning. Quan and Gu (2018) adopted the visualization forms to demonstrate thoughts and discussions during cross-cultural collaborative learning. In addition, Deng et al. (2017) conducted cross-cultural collaboration between two universities and they found that the online discussion was very valuable for enhancing cross-cultural understanding and exchanging perspectives.

Nevertheless, very few studies adopted collaboration scripts during cross-cultural collaborative learning. This study aims to close this research gap and sough to use collaboration scripts to facilitate cross-cultural online collaborative learning. The following sections reviewed previous studies on collaboration scripts.

7.2.2 Collaboration Scripts

Successful cross-cultural collaboration needs more guidance and support (Wang, 2011). Previous studies revealed that scripts had the promising and positive effects on collaborative learning (Fischer et al., 2013; Weinberger et al., 2005). Scripts are composed of play, scene, scriptlet, and role (Fischer et al., 2013). Fischer et al. (2013) also proposed seven principles of the script theory of guidance in computer-supported collaborative learning, including internal script guidance principle, internal script configuration principle, internal script induction principle, internal script reconfiguration principle, trans-activity principle, external script guidance principle, and optimal external scripting level principle. Collaboration script is defined as procedural knowledge that specifies and sequences activities and roles in collaborative learning (Weinberger et al., 2007). Collaboration scripts structured interactions through posing questions, sequencing interactions, and prompting students to engage in particular behaviors (Fischer et al., 2013; Rau et al., 2017). Collaboration scripts contributed to sequencing collaborative learning (Carmien et al., 2007), stimulating interactions (Kolodner, 2007), and providing guidelines of collaboration (Rummel & Spada, 2005). Popov et al. (2013) found that culturally mixed dyads working with the collaboration scripts demonstrated a higher frequency of social interactions. It was found that learning with collaboration scripts had a non-significant positive effect on motivation, a small positive effect on domain learning, and a medium positive effect on collaboration skills (Radkowitsch et al., 2020).

Collaboration scripts have been adopted in the CSCL field to improve learning performance. For example, Heimbuch et al. (2018) compared the effects of two collaboration scripts on learning activities and they found that the script that encouraged participants to discuss any planned changes upfront promoted learning engagement. Schwaighofer et al. (2017) integrated collaboration scripts and heuristic worked examples. They found that the collaboration scripts were appropriate to initially support dialectic mathematical argumentation skills, but might be overwhelming for learners with lower working memory ability. Rau et al. (2017) developed an adaptive collaboration script with multiple visual representations in chemistry and they found that the adaptive collaboration scripts significantly improved learning gains. Splichal et al. (2018) designed an external script to promote reflection during project-based learning and they found that the script significantly promoted regulation of collaboration. Lin (2020) investigated the effects of mastery goal orientation, collaboration script use, computer mediation on learning performance and the results indicated that using collaboration scripts wrote significantly longer reports. However, it is still a lack of knowledge about how to support collaborative knowledge building through collaboration scripts during a cross-cultural collaborative learning. This study aims to close this gap to examine how to facilitate collaborative knowledge building through scripts.

7.3 Method

7.3.1 The Cross-Culture Online Collaborative Learning Design Plan

This study designed a detailed collaborative learning plan to conduct cross-culture online collaborative learning. The topic of collaborative learning was genetically modified food. Table 7.1 shows the details of the collaborative learning plan, including collaborative learning objectives, collaborative learning task, interactive strategies, learning resources, and assessment method. Figure 7.1 shows the target knowledge map. Table 7.2 shows the assessment criteria of group products.

7.3.2 Participants

This study enrolled nine graduate students to conduct online cross-cultural collaboration. Among these 9 students, 3 of them were from Rwanda, Uganda, and Ghanarest and the rest ones were from China. All the participants were divided into 3 groups of three students. For each group, there were one international students and two Chinese students. These 9 participants were females and they never collaborated before.

7.3.3 Procedure

This study conducted online cross-cultural collaborative learning through WeChat. WeChat is a very popular social media tool and it has been widely used in China. This study engaged students in online collaborative learning through WeChat since all of participants are very familiar with the social media tool. All the participants can collaborate anywhere and anytime without extra training. In order to facilitate cross-cultural collaborative learning, the special collaboration scripts were provided through WeChat to guide students to collaborate smoothly. Tables 7.3 and 7.4 are collaboration scripts provided for participants. After they completed the tasks, all of the discussion transcripts were analyzed through IIS-map analysis method to get an understanding of how the scripts support cross-cultural collaborative learning. The collaborative knowledge building level was calculated through the developed algorithm by authors (Zheng et al., 2012).

Table 7.1 The cross-culture collaborative learning design plan

Collaborative learning objectives	• Learners pay attention to the safety of genetically modified food and get better understanding of different views and arguments on the safety of genetically modified food. • Learners should hold rational and realistic attitudes toward the safety of genetically modified food. • Learners are expected to collaboratively build shared knowledge about genetically modified food.
Collaborative learning task	Genetically modified foods are a class of genetically modified organisms. For convenience, we use the acronym "GMF." According to the source of GMF, GMF can be divided into plant source GMF, animal source GMF, and microbial source GMF. For this activity, we will mainly focus on plant source GMF. The crops involved in the plant source include: genetically modified soybeans, genetically modified corn, genetically modified tomatoes, and genetically modified rapeseed. In the global transgenic planting, the area of genetically modified soybeans is up to 258 billion hectares, accounting for 58% of the global GMF. Transgenic technology has brought enormous benefits to human beings, as well as some potential dangers and ethical issues. Due to the differences in the level of GM technology in different countries, the cultural traditions, religious beliefs and values of different countries are not the same, plus the conflict of commercial interests. Governments, scholars, and the public have different attitudes toward GMF. Please collaboratively complete the following sub-tasks: (1) Share the examples of genetically modified foods you know. Discuss what is genetically modified food as well as the differences between GMF and traditional food. And then discuss the advantages and disadvantages of genetically modified foods and support it with evidence and make a summary report. (2) Discuss your country's attitudes and related policies on GMF and share them with fellow members on the group platform, if your country's attitudes toward genetically modified food are basically similar, then find out which countries in the world have other attitudes. (3) Read the passage below, choose one of the following role positions and express your opinion on the role you represent and express your needs and expectations for other social roles. A. Consumer B. Policy maker C. GMF researchers and developers *Brazil nuts have a protein called methionine and cysteine 2S albumin. In order to improve the nutritional quality of soybeans, in January 1994, researchers at Pioneer Seeds of the United States tried to transfer the gene encoding the protein 2S albumin from Brazil nuts into soybeans, but they realized that some people have an allergic reaction to this soybean. The study was subsequently terminated, but soybeans that were transferred to the gene encoding the protein 2S albumin were tested and found to be allergic to this genetically modified soybean.* At the end of the whole task, everyone has learned more about GMF. Now write an article about "A cross-cultural view of GMF" with your group members.

(continued)

Table 7.1 (continued)

Interactive strategies	• You can use brainstorming, jigsaw, argumentation, and so on. • Before the whole task, all of you introduce yourself to each other in order to collaborate better. • Set the groups' collaborative learning goals and assign roles from the column below to each member. • Develop a plan to serve as a guide for accomplishing the task. • At the end of collaborative learning, reflect on group progress, the contributions, the strength, and weaknesses.
Role assignment	• Group leader: coordinates and manages group activities and also ensures all group members contribute to the discussion and tasks. • Information searcher: be responsible for searching information about the topic and the needed resources. • Summarizer: summarizes all the contributions at each stage of the discussion and also puts the final in a word document. • All group members are expected to contribute to discussions irrespective of their roles.
Learning resources	Internet, laptop, web browser, WeChat, and learning materials.
Assessment methods	• Peer assessment • Teacher evaluated the group product according to the criteria.

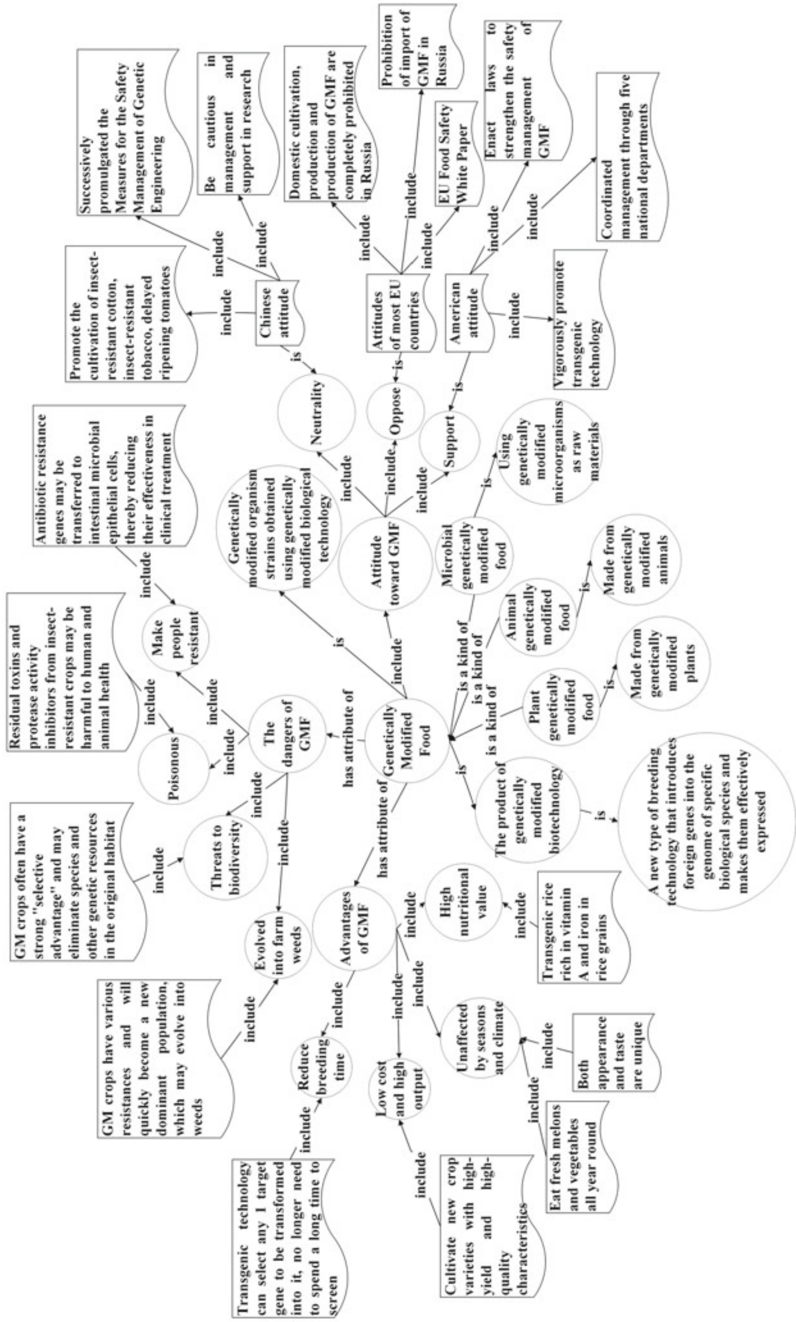

Fig. 7.1 The target knowledge map

Table 7.2 The assessment criteria of group products

Dimensions	Excellent (8–10)	Good (5–7)	Poor (1–4)
Content	The article clearly linked to the theme, provided detailed description, and explained GMF with examples, facts, evidence.	The article clearly linked to the theme, however, it did not provide detailed description and explanation.	The article neither linked to the theme nor explained GMF without evidence.
Language	The article is easy to understand and accurate use of language without grammar errors.	The article is easy to understand and accurate use of language with a few grammar errors.	The article cannot be understood. There are many grammar errors.
Structure	The article is well structured and had good paragraph connection.	The article is well structured, however, it is lack of paragraph connection.	The article is not structured properly and it is lack of paragraph connection.

7.4 Results and Discussion

7.4.1 Analysis of the First Group

In this section, how the first group collaboratively build knowledge and complete the group products was analyzed in depth. Initially, the group members introduced themselves and discussed the role assignment based on their specialty. Then they discussed the task requirements and set the collaborative learning goal with the help of scripts. After they set the learning goals, they begun to share information, link what they have learned with new information to co-construct knowledge together. After that, they discussed the attitudes toward genetically modified food. Finally, they summarized what they have discussed and written an article about a cross-cultural view of genetically modified food. Figure 7.2 shows the knowledge graph generated by the first group. It can be found that this group got the better understanding of genetically modified food. The knowledge-building level achieved 150.93. In addition, the group products got 80.

7.4.2 Analysis of the Second Group

In the beginning, the second group members discussed the role assignment. And then they discussed the learning goal. But they set the wrong learning goal. They believed that "our goal is to write an article about GMF." However, the correct learning goal is shown in Table 7.1. An article is a group product rather than the learning goal. Since this group set the wrong learning goal, they took lots of time to discuss how to write this article. They did not build knowledge together and only two members contributed and discussed. Figure 7.3 shows the knowledge graph generated by the second group. The knowledge building level only achieved 76.97. The group products got 69. It can be found that this group got the superficial understanding of genetically modified food. The reason of failure lay in that they did not make use of scripts to guide them to collaborate.

Table 7.3 The collaborative learning scripts

Phases	Scripts
Set learning goals	Set the collaborative learning goals as a team and assign roles to each other. • In terms of goals, think of what an expert would do and what you will do in the process of accomplishing this task. • In terms of role assignment, each team member should choose one of the roles.
Make plans	Develop a plan for the collaborative learning task and individual roles. To do this, please answer the following questions: • Think of what to do to achieve the learning goals? • Why (determine the purpose or agenda)? • How (participation, source, tools, types, roles, text, and share)? • When (time and duration)? • Who (roles and audience)?
Monitor collaborative learning activity	• For the first sub-task, when expressing your opinions, the logic should be clear, the core ideas should be concise, and the facts and cases should be used to explain. • For the second sub-task, learn about your country's attitudes toward GM foods and related policies through the Internet. Share them with your group members and compare with each other. Ask for further clarification if you don't understand what your group members shared. • For the final product, think of writing as a researcher and as a blogger. What information types will you include in the short article and what makes your information valid and reliable? Summarize your writings in a word document and share them on the group platform. Remember to do this in a step-by-step way as a team and include examples.
Reflect and evaluate	• Evaluate the group product ahead to submission and refine it. • Think of your work progress, the contributions, your group strength, and weaknesses.

Table 7.4 The scripts for how to collaborate

Items	How to collaborate
Do's	All communications should be carried out through WeChat.
	All team members should work with your group goals.
	Get to know each other (individual background introduction).
	Build trust for each other as a team.
	All team members should be open about everything.
	Try your best to communicate with your team members about your challenges and positive experiences during task execution.
	All members should support disagreements, agreements, confirmations, and arguments with reasons.
	When individual ideas are challenged, support your ideas, or contributions with evidence or clarify.
	Be each other's keeper and keep encouraging each other.
	When you are stuck or do not understand anything, ask the group members for help.
	Assist team members politely.
	Overall, try to build a team culture.
Don'ts	Do not decide to do the group work with your individual goals.
	Don't neglect your role.
	Don't think your group members are contributing and therefore yours is not important.
	Don't communicate via audio nor group call.
Sentence openers	When discussing with your group members, try to use the following sentence opening words or phrases: To manage the interaction, you can start with ✓ Can we start.., Where do we start.., What should.., Are we.., Can you.., May we know.. To be in agreement/support or disagree/challenge ✓ I agree because.., that's right, good point, Ok but.., Yes, Yes but.., I disagree with you because.., I agree because.., to summarize To give a contribution or ask for clarification ✓ Can I explain.., can I elaborate.., can you explain.., can I suggest, I want to.., can we consult.., let's support with..

7.4.3 *Analysis of the Third Group*

The third group began with the help of scripts about how to collaborate. One of the members asked, “Shall we start?”. Then they introduced themselves and begin to set learning goals with the help of scripts. The third group set the right learning goal, namely, they need to discuss the definition, difference, advantages, and disadvantages of GMF as well as different attitudes toward GMF. Then all of the group members co-constructed knowledge together based on the learning goal and the provided scripts. The whole collaborative learning process was very smooth and they helped each other. After collaboration, they all believed that “We are a great and wonderful team.” Figure 7.4 shows the knowledge graph generated by the third group. The knowledge building level achieved 182.8. In addition, the group products got 90. It can be found that this group got the deeper understanding of genetically modified food than the first group.

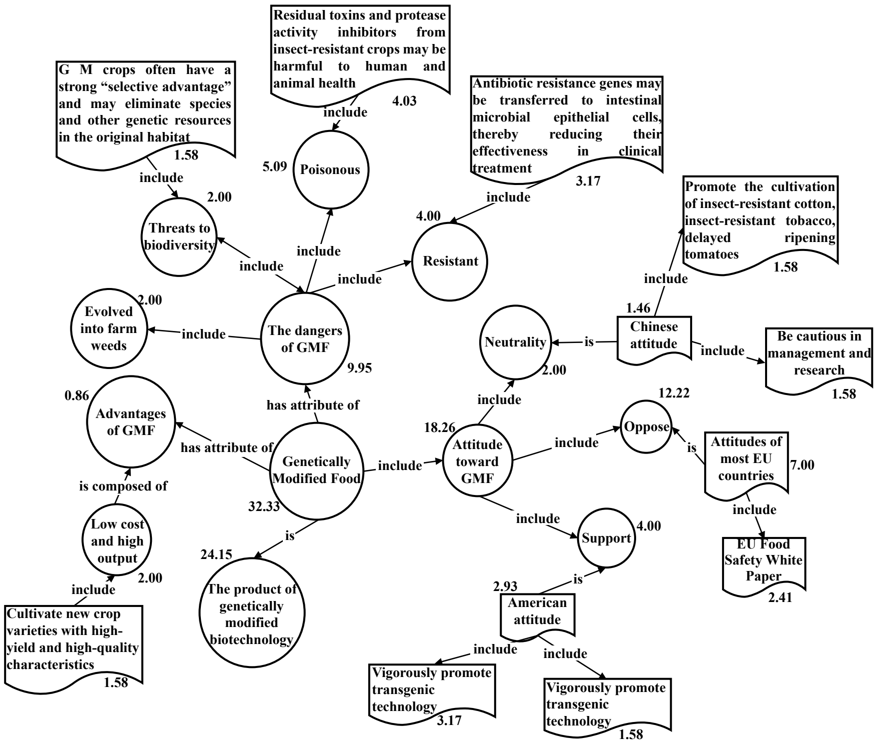

Fig. 7.2 The knowledge graph generated by the first group

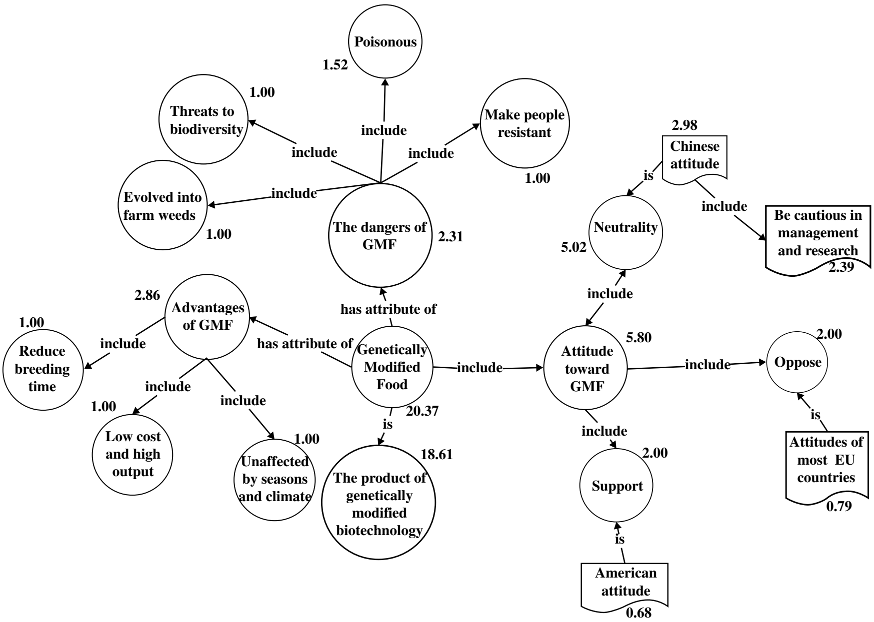

Fig. 7.3 The knowledge graph generated by the second group

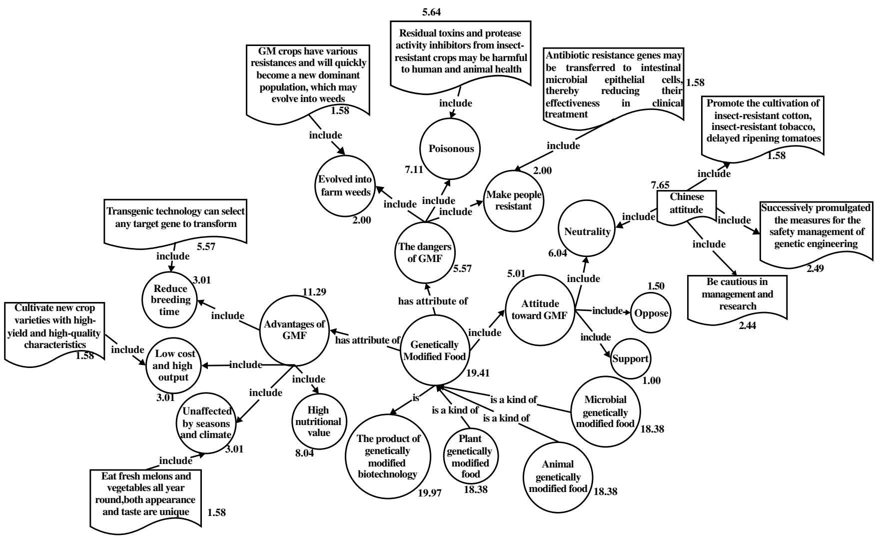

Fig. 7.4 The knowledge graph generated by the third group

7.4.4 Interview Results

To get a better understanding of the role of scripts, the semi-structured interview was conducted after collaboration. First, all of the interviewee believed that the provided scripts were very useful for facilitating cross-culture collaborative learning. The main reason was that the scripts provide the guidelines about how to collaborate better. For example, one of the interviewee stated that “We don’t know each other and don’t collaborate before. With the help of script, we can start, proceed, negotiate, and solve problems together. The collaboration scripts are very useful and helpful.” Second, the interviewee believed that cross-culture collaborative learning was hindered by language because the mother language of group members is different. Thus, there are some barriers of communication to solve this problem, they made use of the provided scripts about how to collaborate to initiate and push the discussion step by step. As one interviewee said that “I believed that the sentence openers are very helpful. To promote collaborative learning, the scripts about what we should do and what we should not do are also very useful. Our group start and go ahead with the help of the provided scripts.” To sum up, the collaboration scripts are very effective for the cross-culture collaborative learning.

7.4.5 Implications

This study revealed that cross-culture collaborative learning can be facilitated through the well-designed scripts. However, the cross-culture collaborative learning was hindered by language and unfamiliarity of mutual culture. To facilitate cross-culture collaborative learning, the following suggestions and implications are proposed.

First, teachers and practitioners should design collaboration scripts to support cross-culture collaborative learning. More specially, the intercultural enriched collaboration script should be developed to tailor to the diverse cultural backgrounds of learners (Popov et al., 2019). As Popov et al. (2019) proposed that collaboration scripts for individualist and collectivist should be designed to maximize the effects of cross-culture collaborative learning. The intercultural enriched collaboration scripts mainly include social scripts, cognitive scripts, and metacognitive scripts. These three kinds of scripts need to be designed elaborately based on the collaborative learning tasks and learners’ characteristics.

Second, individual differences have an impact on collaborative knowledge-building level in cross-culture collaborative learning. The individual differences include the differences in prior knowledge, regulation skills, cultural background, experiences of collaborative learning, and so on. Therefore, teachers and practitioners should form the heterogeneous groups to balance the individual differences. In addition, the particular activities such as cultural awareness activity can minimize the individual differences to enhance cross-culture collaborative learning (Kumi-Yeboah, 2018).

Third, it is suggested that advanced tools should be developed to promote cross-culture collaborative learning. With the development of machine learning, groups' discussion transcripts can be analyzed automatically to identify the problems during collaborative learning. Thus, collaborative scripts should be more adaptive based on the problems and progress of each group. It was found that adaptive collaborative scripts improved learning gains (Rau et al., 2017) and the regulation process (Wang et al., 2017). Therefore, adaptive collaborative scripts should be developed further to facilitate cross-culture collaborative learning.

7.5 Conclusions

This study examined the role of collaboration scripts through three cases in cross-culture collaborative learning context. The qualitative and quantitative analysis results indicated that collaboration scripts were very useful and helpful for facilitating collaborative knowledge building in cross-culture collaborative learning.

However, caution should be made when generalized the results. First, this study only analyzed three groups' cross-culture collaborative learning processes and collaborative knowledge-building levels. Therefore, the sample size was very small. Future studies should conduct a large-scale cross-culture collaborative learning to examine the impacts of scripts. Second, this study only examined the effects of scripts on collaborative knowledge building and group products. Future study will examine the impacts of collaboration scripts on engagement, behaviors, and metacognition. Third, this study designed the fixed scripts to support cross-culture collaborative learning. Future study will develop and examine the effects of adaptive and personalized scripts to facilitate cross-culture collaborative learning.

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Chapter 8
Promote Collaborative Knowledge Building Through Teacher Guidance

Abstract Collaborative knowledge building has been an important pedagogical approach in K-12 and higher education. However, collaborative knowledge building cannot occur spontaneously and need to be guided by teachers. This study examined teacher scaffolding supported collaborative knowledge building practices in the online learning environment. Totally 94 undergraduate students participated in this study and they were randomly assigned into 12 experimental groups and 13 control groups. The teacher provided real-time guidance only for the experimental group to promote collaborative knowledge building. The control groups carried out knowledge building by themselves. The results indicated that there were significant differences in collaborative knowledge building and knowledge convergence between the experimental group and control group. The experimental group outperformed the control group in terms of collaborative knowledge building and knowledge convergence degree. The results together with the implications for teachers and practitioners are discussed in depth.

Keywords Collaborative knowledge building · Teacher guidance · Knowledge convergence

8.1 Introduction

Knowledge building has been an innovative pedagogical approach in K-12 and higher education. Previous studies revealed that knowledge building is conducive to collaborative learning (Hong & Lin, 2019). Knowledge building is the process of "production and continual improvement of ideas of value to a community" (Scardamalia, 2003). Knowledge building is a principle-based and idea-centered approach to enable students in improving ideas together (Scardamalia & Bereiter, 2010). Stahl (2000) proposed a model of knowledge building, including articulating personal comprehension in words, forming public statements, integrating other

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people's public statements, discussing alternatives, argumentation, clarifying meanings, constructing shared understanding, negotiating perspectives, building collaborative knowledge, formalizing and objectifying, and forming cultural artifacts. This model is very insightful for implementation of knowledge building in practice.

Collaborative knowledge building involves mutual exploration of issues, questioning together, interacting with each other, and building on others' ideas (Harasim, 1989; Muhonen et al., 2017). Collaborative knowledge building (CKB) is a processes of creating knowledge by group members or community together. Collaborative knowledge building is focused on learners' engagement in the generation, communication, reflection, and improvement of ideas to create knowledge together (Hong & Lin, 2019). That is to say learners need to collaboratively create new valuable knowledge for a community. It was found that collaborative knowledge building contributed to improving the third graders' reading comprehension skills compared with the traditional direct instruction (Hong et al., 2020). Collaborative knowledge building contributes to effective scientific inquiry and developing more sophisticated scientific concepts (Li et al., 2020).

However, it was found that collaborative knowledge building is not easily to achieve since it need to continual improvement of ideas and advancing knowledge by the community (Arvaja et al., 2007; Chen & Hong, 2016). Lin and Reigeluth (2016) proposed that it was necessary to provide scaffolding for intersubjectivity and autonomy to support collaborative knowledge building. Furthermore, Ghazal et al. (2019) found that online facilitator should provide adaptive support for learners to promote collaborative knowledge building. Therefore, teachers' guidance is very necessary for facilitating collaborative knowledge building. It was found that teacher guidance was positively related to collaborative learning (van Leeuwen & Janssen, 2019). This study aims to promote collaborative knowledge building through teachers' guidance in CSCL context. The research questions are addressed as follows:

RQ1: What are the differences in collaborative knowledge building level between the students learning with teachers' guidance and those learning without teachers' guidance?

RQ2: What are the differences in group product quality between the students learning with teachers' guidance and those learning without teachers' guidance?

8.2 Literature Review

8.2.1 Collaborative Knowledge Building

The mission of knowledge building is to enable education to be a knowledge creation enterprise (Scardamalia & Bereiter, 2003). Knowledge building represents an attempt to initiate students into a knowledge creating culture (Scardamalia &

Bereiter, 2006). Knowledge building occurs when all participants took collective responsibilities for creating new knowledge and learning (Rogoff et al., 1996). Scardamalia (2002) proposed 12 principles of knowledge building, including real ideas and authentic problems, improvable ideas, idea diversity, collective responsibility, epistemic agency, democratizing knowledge, rise above, constructive use of authoritative sources, pervasive knowledge building, knowledge building discourse, symmetric knowledge advance, embedded, and transformative assessment. These 12 principles guide teachers to help students to perform collective sociocognitive responsibility to promote knowledge building (Chen & Hong, 2016).

In collaborative knowledge building, group activity should be structured (Palincsar & Herrenkohl, 2002) and the discourse should be progressive (Hmelo-Silver & Barrows, 2008). It was found that the social and cognitive systems involved in collaborative knowledge building interconnected with each other (van Heijst et al., 2019). Therefore, the sociocognitive dynamics of collaborative knowledge building should be motivated and tracked to facilitate productive knowledge building. In addition, teachers play a very crucial role to facilitate collaborative knowledge building. Teachers can propose questions or prompts to support collaborative knowledge building as well as encourage learners to be responsible for their own learning and others' learning (Hmelo-Silver & Barrows, 2008). Teachers can design learning activities to enable collaborative knowledge building occur. Teachers also play important role for optimizing affordances in collaborative knowledge building (Tan et al., 2021).

8.2.2 Knowledge Convergence

Knowledge convergence is conceptualized as the processes of learners co-constructing common knowledge and obtaining the similar understanding of subject matter (Zheng et al., 2014). Knowledge convergence represents to what extent learners share knowledge (Weinberger et al., 2007). Knowledge convergence occurs when sharing knowledge, identifying differences, and negotiating transitively (Onrubia & Engel, 2009). It was found that improved group communication increased knowledge convergence (Dehler et al., 2011). Halatchliyski et al. (2011) found that cognitive conflict is pivotal for the emergence of knowledge convergence.

As Roschelle (1996) stated that learners' mutual influence and convergence is very crucial for successful collaborative learning. It was found that learners who converged in knowledge achieved better learning achievements than learners who do not (Fischer & Mandl, 2005). Mercier (2017) revealed that students with a learning goal demonstrated more knowledge convergence than those with a performance goal. However, knowledge convergence cannot occur spontaneously and it needs to be guided and facilitated by teachers or practitioners. Teachers and practitioners can guide learners to set learning goals and conduct socially shared regulation to achieve knowledge convergence.

8.2.3 Teacher Guidance in CSCL

Collaborative learning is characterized as positive interaction among learners (Johnson & Johnson, 2009). Previous studies indicated that collaborative learning contributed to achieving higher learning outcomes than individual learning (Chen et al., 2018; Kyndt et al., 2014). However, teachers need to provide guidance to achieve the positive effects (Kaendler et al., 2015; van Leeuwen & Janssen, 2019). During collaboration, teachers need to monitor the collaborative learning processes and intervene when necessary (Van de Pol et al., 2015). It was found that teachers need to prepare students for collaborative learning, structure group interactions, provide scaffolding, and interact with students during collaborative learning to promote productive dialogue (Webb et al., 2019). Therefore, teachers play a very crucial role in productive collaborative learning. However, little is known that whether or not teachers' guidance had impacts on collaborative knowledge building and knowledge convergence. The present study sought to examine the effects of teachers' guidance on collaborative knowledge building and knowledge convergence through an empirical study that lasted for one month. The following sections will illustrate how the study was conducted and the results as well as implications.

8.3 Method

8.3.1 Participants

Totally 94 undergraduate students participated in this study. There were 13 males and 81 females. They major in Chinese language and literature as well as communication. All of the participants were freshmen and they never collaborated before. They were randomly divided into 12 experimental groups and 13 control groups. Each group is composed of three to four students.

8.3.2 The Collaborative Learning Task

The collaborative learning task was to make a professional website through Dreamweaver. Each group can select and decide the topic of website. The webpages were displayed through layer layout and cascading style sheet. There were texts, images, flash, and pop-up windows within each webpage. All the webpages should be compatible with different browsers. All the groups completed same collaborative learning task for four weeks. The group product was a professional website made by the student themselves.

8.3.3 Procedure

The procedure of this experiment included three steps. First, all of the participants conducted the pre-test about prior knowledge. The result of the pre-test indicated that there was no significant difference in prior knowledge between the experimental group and control group ($t = 0.495$, $p = 0.626$). Second, 25 groups conducted online collaborative learning for four weeks through QQ. QQ is a popular social media tool in China and it has been widely used in higher education. For the 12 experimental groups, teachers provided guidance to promote knowledge building and knowledge convergence. For the 13 control groups, teachers did not provide guidance. Table 8.1 shows the teacher's guidance for the experimental groups. Third, all of the participants completed the same collaborative learning tasks and submitted group products to online learning platform by the end of the fourth week. Teachers evaluated the group products using the same criteria (Fig. 8.1).

Table 8.1 The guidance provided by teachers

Dimensions	Guidance
Knowledge building	• Present the target knowledge map (Fig. 8.1). • Propose cognitive and metacognitive questions. • Provide prompts. • Provide abundant learning resources about how to make a professional website. • Provide the real-time guidance including how to insert a hyperlink, how to add the pop-up window, and so on. • Remind each group member to be responsible for their own and others' learning.
Knowledge convergence	• Provide guidance to promote knowledge convergence, including how to set learning goals, make plans, monitor collaborative learning process, evaluate, and reflect collaborative learning process and outcomes. • Guide students negotiate trans-actively to achieve shared understanding. • Provide real-time feedback about discussion duration, interactive frequency, problems, and solutions to achieve knowledge convergence.

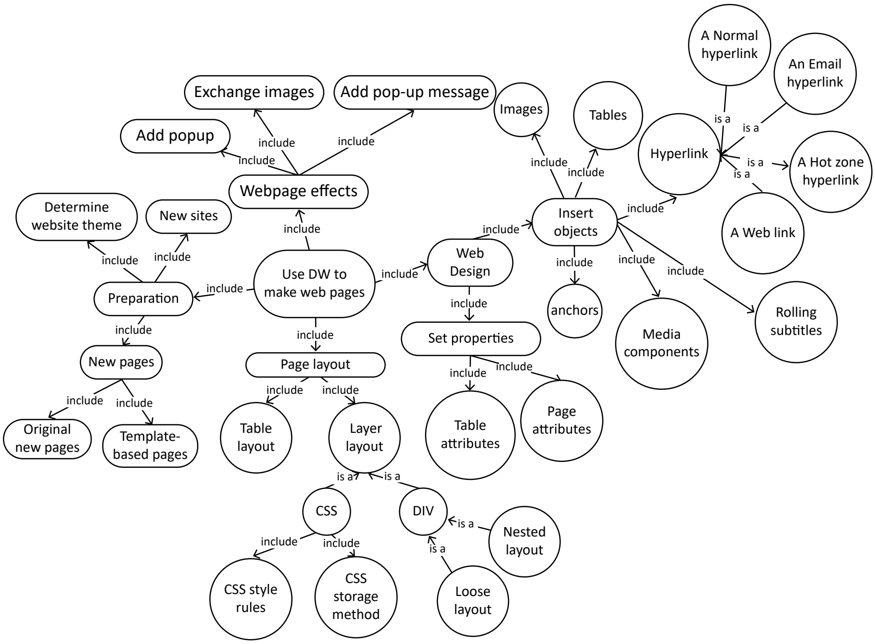

Fig. 8.1 The target knowledge graph

8.3.4 Data Analysis Method

The collaborative knowledge-building level was analyzed in terms of knowledge building and knowledge convergence. The knowledge building level can be calculated through the total activation quantity of the knowledge graph. The details of the algorithm can be found in a previous paper published by Zheng et al. (2012). The knowledge convergence level can be calculated through the algorithm developed by Zheng (2017). The group products were evaluated in terms of multimedia demonstration, content, applicability, perceived ease of use, and compatibility.

8.4 Results and Discussion

8.4.1 Analysis of Collaborative Knowledge Building

This study analyzed collaborative knowledge building of the experimental group and control group. As shown in Table 8.2, the means of knowledge building were 146.08 for the experimental group and 66.98 for the control group. The results of ANCOVAs revealed that there were significant differences in knowledge building ($F = 5.488$, $p = 0.029$) between the experimental group and control group. This finding also revealed that teachers' guidance had an impact on collaborative knowledge building. Figures 8.2 and 8.3 show the knowledge graphs of the experimental group and control group, respectively. The main reason lay in that teachers provide guidance for the experimental group in terms of how to building knowledge together.

Table 8.2 Summary of ANCOVA on collaborative knowledge building

Dimensions	Group	*N*	*M*	*SD*	*F*
Knowledge building	Experimental group	48	146.08	102.50	5.488
	Control group	46	66.98	58.99	

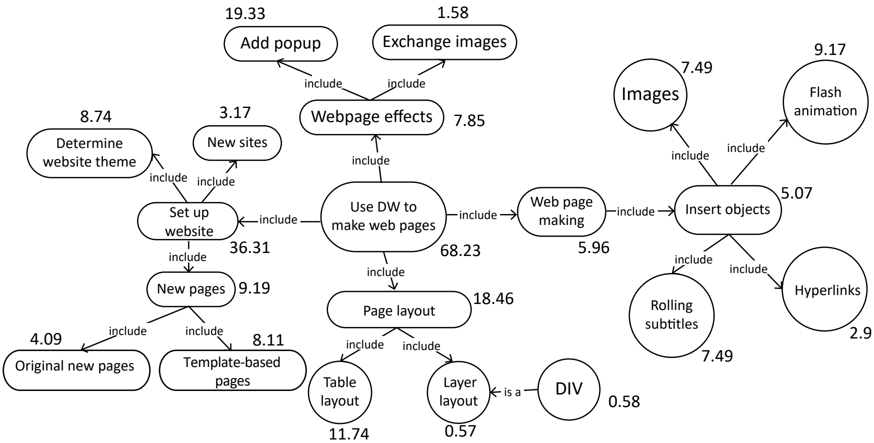

Fig. 8.2 The knowledge graph of an experimental group

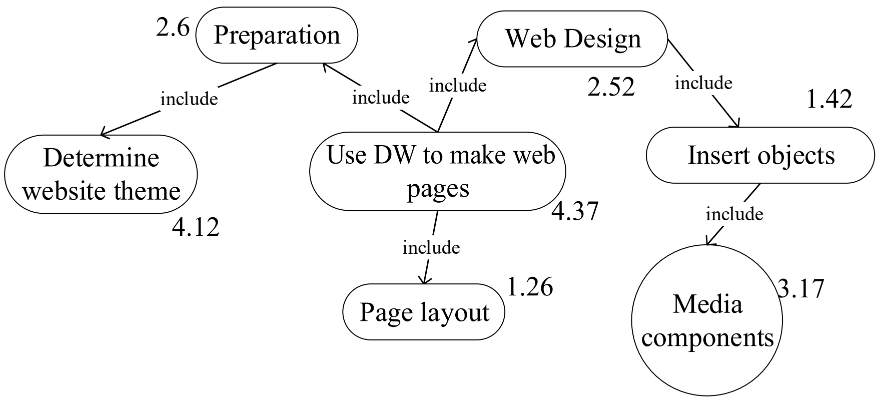

Fig. 8.3 The knowledge graph of a control group

Table 8.3 Summary of ANCOVA on knowledge convergence

	Group	*N*	*M*	*SD*	*F*
Knowledge convergence	Experimental group	48	71.67	51.61	10.102
	Control group	46	19.85	33.51	

8.4.2 Analysis of Knowledge Convergence

This study analyzed knowledge convergence degree of the experimental group and control group. As shown in Table 8.3, the means of knowledge convergence were 71.67 for the experimental group and 19.85 for the control group, respectively. The results of ANCOVAs revealed that there were significant differences in knowledge convergence ($F = 10.102$, $p = 0.004$) between the experimental group and control group. This finding also revealed that teachers' guidance had an impact on knowledge convergence.

8.4.3 Interview Results

To get a deep understanding of learners' perceptions about teachers' guidance, six students were randomly selected to conduct a semi-structured interview. First, all of the interviewee believed that teachers' guidance was very helpful and useful for collaborative knowledge building. For example, S1 indicated that "I really need the teachers' help when I encounter problems and challenges. Our group members initially don't learn together but they only do their own task. Later, our teacher reminded us to be responsible for others' learning to maximize the whole groups' performance. And then we collaboratively to construct knowledge one step by step."

Another student stated that "Our group cannot solve problems by ourselves. It is our teacher who provide real-time feedback and help solve problems. I truly appreciate teachers' help and guidance."

Second, all of the interviewee believed that teachers' guidance was very efficient and effective for knowledge convergence. As S3 stated that "Our group members are often off-topic and talking about some personal affairs. It is our teacher who remind us to converge and focus on collaborative learning tasks." S5 also addressed that "Initially, our group members had different ideas and we don't know how to negotiate to achieve common understanding. Later, our teacher provided some suggestions to guide us to discuss based on the shared understanding. Finally, we got some converged and shared ideas. It is full of achievement. I enjoy the process."

8.4.4 Implications

This study had several implications for teachers and practitioners. First, teachers and practitioners should have a belief that students can create new knowledge of value to a community. Scardamalia and Bereiter (2006) believed that knowledge building can only succeed if teachers believe that students can create new knowledge that is useful for a community. Therefore, teachers and practitioners should establish this kind of belief through productive collaboration with students.

Second, teachers should design authentic and interesting learning tasks to stimulate students to generate new ideas. Scardamalia and Bereiter (2006) found that the reasons for knowledge building failure lay in a failure to deal with problems and elicit real ideas. Therefore, teachers should help students to deal with problems through explanation, reminder, and illumination. The most important is that the appropriate and real-life learning tasks should be designed elaborately in advance to motivate students to produce new ideas. Furthermore, sustained idea improvement is dependent on collective responsibilities and principle-based knowledge-building analytic tools (Hong et al., 2015). Thus, teachers and practitioners should foster students' collective responsibilities and adopt collaborative knowledge-building tools to support knowledge building.

Third, teachers should be facilitators rather than actors for knowledge building. Teachers' role has been changed from knowledge telling to facilitator during knowledge building (Chen & Hong, 2016; Hmelo-Silver & Barrows, 2008). For example, teachers encourage students to generate new ideas and improve ideas continually by themselves. Teachers can provide abundant resources and kind reminders for students to advance knowledge for a community. Teachers help to negotiate conflicts to promote knowledge building further.

8.5 Conclusions

This study examined the effects of teacher guidance on collaborative knowledge building and knowledge convergence in online collaborative learning. It was found that the groups learned with teacher guidance outperformed those who learned without teacher guidance in collaborative knowledge building and knowledge convergence. The interview results also validated the findings.

The generalization of the findings of the present study should be cautious due to the several limitations. First, this study only focused on one collaborative learning task to build knowledge. Although the challenge and complexity of this task, future studies should design other tasks and problems to examine the findings. Second, the present study only examined the impacts of teacher guidance on knowledge building and knowledge convergence. Future studies need to examine the impacts of teacher guidance on socially shared regulation skills and other aspects. Third, teachers' guidance was present during the whole collaborative learning process. In fact, teachers' guidance should be faded when students are equipped with the abilities of knowledge building. Future studies should focus on how to foster students' autonomy in advancing knowledge.

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Part III
Assessment and Optimization of CSCL Design Based on Design-Centered Approach

Chapter 9
An Innovative Method of Evaluating Collaborative Learning Design Quality

Abstract Design is one of the important attributes of teaching and learning. However, how to design collaborative learning activity has been neglected for a long period. This chapter highlighted the importance of design and proposed an innovative method of evaluating the design quality of CSCL activity. This method has been validated by a number of design plans of CSCL activity. The results indicated that the alignment between collaborative learning goal and task design, media diversity, the adaptability of goal design, and the adaptability of task design can evaluate the design quality of collaborative learning plan. The optimization strategies were proposed to improve the design quality of collaborative learning plan. The findings of this study provided valuable references for front-line teachers to design high-quality CSCL activities in future.

Keywords Collaborative learning · Design quality · Learning goal

9.1 Introduction

With the rapid development of technology, knowledge sharing, and dissemination has devolved to Internet. Therefore, teachers have to redefine their roles (Maina et al., 2015) from "sage on the stage to guide on the side" (King, 1993) to "designers for learning" (Goodyear & Dimitriadis, 2013). Design is very important in the field of education but it is often neglected. Simon (1969) was the first one who proposed that design is a science and design science is the science of the artificial science. Different from natural science that focuses on what it is, the design science focuses on what should be (Simon, 1969). The nature of design is reflected in both art and science (Maina et al., 2015).

In recent years, learning design gained more and more attention in the society of information. Learning design was conceptualized as the creative act of plans of activity, resources, and tools to achieve educational aims (Mor & Craft, 2012). Learning design is concerned with how to design learning activities and interventions to help teachers or designers to make informed decisions (Conole, 2013). As Lockyer et al. (2013) stated that learning design represents the sequences of tasks

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and teaching methods. A crucial principle of learning design is to make the design process more shareable and replicable (Conole, 2013). Learning design is very crucial since it provides the framework for analyzing and interpreting learners' behaviors and learning patterns (Mangaroska & Giannakos, 2018). The purpose of learning design has twofold. One is to support educators to make decisions (Conole, 2013; Mangaroska & Giannakos, 2018), another is to orchestrate learning design activities (Mangaroska & Giannakos, 2018; Prieto et al., 2015).

Currently, there are two approaches to design in the field of education. One approach is design-based research (DBR), another approach is design-centered research (DCR). Design-based research focuses on the effectiveness of interventions (Design-Based Research Collective, 2003) and involves multiple aspects of the design as well as flexible design revision (Barab & Squire, 2004). For example, Lyons et al. (2021) adopted two cycles of design-based research to develop a web-based tool for fostering social regulation in collaborative learning. However, the results of design-based research are difficult to replicate since design-based research was impacted by researchers' subjectivity and bias (Anderson & Shattuck, 2012) as well as local context (Design-Based Research Collective, 2003). Different from design-based research, design-centered research highlights the importance of design and the synergy between design and implementation (Yang, 2013). Design-centered research aims to generate technological knowledge about design through the analysis of design deficiency (Yang, 2013). To replicate the findings in other contexts, this study adopted the design-centered research to evaluate the design plan of collaborative learning.

9.2 Literature Review

9.2.1 The Studies on CSCL

Collaborative learning has attracted lots of researchers from different fields to make contributions. There are many factors that impacted the effectiveness of collaborative learning. For example, group size (Pfister & Oehl, 2009), division of labor (Kato et al., 2004), team-skills (Prichard et al., 2006), quality of initial postings (Ioannou et al., 2014), students' attitudes toward collaborative learning (Ku et al., 2013), and social as well as cognitive factors (Van den et al., 2006). To achieve high-quality collaborative learning, these factors need to be designed elaborately and orchestrate in ahead of implementation. Orchestration was defined as the process of coordinating interventions among multiple learning activities occurring at different social levels (Dillenbourg et al., 2009). Teachers should orchestrate learning activities to achieve a maximum effect (Prieto et al., 2015). For example, Wen (2019) designed orchestration cards to help teachers orchestrate collaborative learning in classrooms.

Collaborative learning is a field of understanding human development that comprises social interaction and artifacts involved in meaning making (Ludvigsen & Steier, 2019). Intersubjectivity creates the conditions for humans to communicate, learn, and developing rationality in society (Ludvigsen & Steier, 2019). Furthermore, Wise and Schwarz (2017) proposed eight provocations for the future of collaborative learning field, including uniting diverse tools and theories, prioritizing learner agency over collaborative scripting, securitizing collaboration and community, pursuing of computational approaches to understand collaborative learning, reconciling analytical and interpretative approaches to understanding collaboration, adopting learning analytics and adaptive support, focusing on social media and large-scale learning environments, and achieving tangible change in the education system.

Currently, computer-supported collaborative learning (CSCL) focus on CSCL environment (Cress, 2020), building community together (Rosé & Järvelä, 2020), and group interaction in the age of COVID-19 (Järvelä & Rosé, 2020). For example, Zhang et al. (2020) explored boundary-crossing interactions between two grade 5/6 science classrooms to promote knowledge building with the aid of Knowledge Forum.

Yoon et al. (2020) examined a design and development approach to improving science teachers' professional development through building community in an online asynchronous environment. They found that higher levels of collaborative discourse promoted teachers to reflect on content understanding and classroom practice. Saqr et al. (2020) analyzed a dataset of 12 university courses through social network analysis and they found that degree centralities were reliable indicators for students' participatory efforts and a predictor of learning performance.

9.2.2 Collaborative Learning Design

Collaborative learning design is a process for planning how collaborative learning unfolds step by step. It was found that collaborative learning design was often based on subjective experiences about pedagogy, technology, or the concept of collaborative learning (Strijbos et al., 2004). Thus, Strijbos et al. (2004) identified six elements that affect collaborative learning, including learning objectives, task-type, group size, computer support, and pre-structure level. Pozzi and Persico (2013) proposed a model of collaborative learning design to support pedagogical planning and decision making, which include time, task, team, and technology.

In addition, some researchers adopted activity theory to design collaborative learning activity. For example, Collis and Margaryan (2004) designed work-based collaborative learning activities based on the activity theory framework to promote the construction of knowledge. Lewin et al. (2018) designed collaborative learning lesson plan, in which subject (teachers), object (digital pedagogy), rules, community, division of labor, and artifacts were clearly indicated to promote teachers' collaboration. Additionally, Järvenoja et al. (2020) built on the flipped classroom and conducted collaborative learning design to promote the awareness of motivation, emotion, and their regulation in science classroom.

Furthermore, some researchers focused on script design to promote structured collaborative learning. Scripts are designed to support collaboration among peers in the field of collaborative learning since the rationale of scripts are to structure collaborative learning to trigger interactions (Dillenbourg & Tchounikine, 2007). Scripts can be classified into macro-scripts that are coarse-grained scripts of creating learning situations and micro-scripts that are fine-grained scripts of emphasizing individual activities (Dillenbourg & Tchounikine, 2007). However, scripts were also criticized for inflexibility and potential risks of over-scripting (Demetriadis & Karakostas, 2008). Therefore, the adaptive scripts were developed to tailor to group characteristics. For example, Amarasinghe et al. (2019) conducted predictive analysis through machine learning algorithm to form the adaptive scripts to adapt to the activity participation differences.

However, previous studies put emphasized how to design collaborative learning activity through social scripts (Weinberger et al., 2005), online learning environment (Wyai et al., 2020), or mobile APPs (Petko et al., 2019). To the best of our knowledge, it is a lack of evaluating quantitatively the design quality of collaborative learning. To close this gap, this study aims to develop an innovative method of evaluating collaborative learning design plan. The following sections will illustrate the method, procedures, and results in depth.

9.3 Method

9.3.1 CSCL Tasks

This study designed four collaborative learning tasks about artificial intelligence for junior middle school students. The learning objectives of these tasks was to help students to get a better understanding of concepts and principles of artificial intelligence. Students also need to program to achieve the particular functionalities using Simba (see Fig. 9.1). Simba is revised and developed based on Scratch. More details about Simba can be found on the website: https://simba.kenschool.com.cn/.

The first collaborative learning task was to make an electronic photo album with picture rotation, music, and speech recognition. The second collaborative learning task was to conduct optical character recognition and design an optical character recognition program. The third collaborative learning task was to develop a game of Whac-A-Mole with speech recognition. The fourth collaborative learning task was to develop a game of feeding frenzy using Simba.

9.3.2 Participants

Participants were from a junior middle school in Beijing, China. There were 39 students (class 1) who participated in the first round collaborative learning and 37 students (class 2) who participated in the second round collaborative learning. The result of the pre-test for these two classes revealed that there was no significant difference in prior knowledge about artificial intelligence ($t = 1.019$, $p = 0.312$).

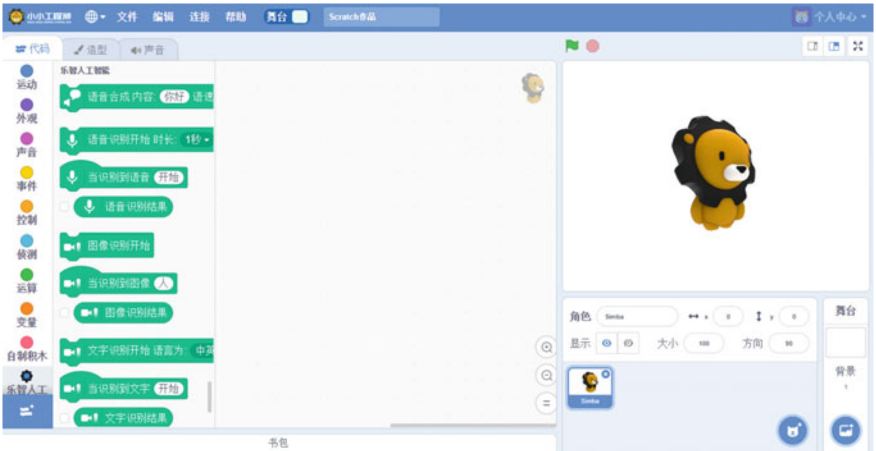

Fig. 9.1 The screen shot of Simba

9.3.3 Collaborative Learning Design Plan

The topic of collaborative learning design plan was to design an optical character recognition program. This design plan included collaborative learning goals, target knowledge map, collaborative learning task, interactive approach, learning resources, and assessment method. Table 9.1 shows the details of the design plan for the first round collaborative learning.

9.3.4 The Evaluation Method

This study developed the four indicators to evaluate the design quality of collaborative learning plan, including the alignment between collaborative learning goal and task design, media diversity, the adaptability of goal design, and the adaptability of task design. The following will illustrate the algorithm of the four indicators through an example.

The alignment between the collaborative learning goal and task design represents the consistency between the collaborative learning goal and task design. It is measured by the similarity between the target knowledge map and the knowledge map activated by the collaborative learning task. This study proposed an improved algorithm to measure the similarity of the two maps based on previous study (Zhu et al., 2004). The alignment between the collaborative learning goal and task design can be calculated using the formula (9.1).

Table 9.1 The collaborative learning design plan of the first round

Dimensions	Content
Collaborative learning goals	• Low-difficulty goal: get a better understanding of the concept and applications of optical character recognition. • Medium-difficulty goal: acquire the principles and characteristics of optical character recognition as well as experience optical character recognition through artificial intelligence platform. • High-difficulty goal: design an optical character recognition program to make a background music. Design an optical character recognition program integrating with face recognition or speech recognition.
Target knowledge map	See Fig. 9.2
Collaborative learning task	• Low-difficulty sub-tasks: Please compare the speed of character recognition by human and by machine. Please compare the accuracy of character recognition by people and by machine. • Medium-difficulty sub-tasks: Please summarize the process of character recognition by a human. Do you know the process of character recognition by machine? Please provide some examples of optical character recognition. Please experience optical character recognition through Baidu artificial intelligence platform. • High-difficulty sub-tasks: design an optical character recognition program to make a background music. Design an optical character recognition program with face recognition or speech recognition through Simba.
Interactive approach	• The interactive strategy included brainstorm and discussion. The group members discussed and everyone expressed their opinions • The role included the organizer, monitor, and summarizer. The organizer was responsible for facilitating the whole collaborative learning process and guiding all group members to complete the task The monitor was responsible for criticizing group members' ideas and provided suggestions. The summarizer was responsible for summarizing the main ideas of programming and guiding group members to reflect collaborative learning process and group products.
Learning resources	Learning resources included program software Simba, Baidu artificial intelligence platform, and questionnaire. The scaffolding included the task list and learning materials about optical character recognition.
Assessment method	The teacher evaluated group products based on the assessment criteria. The group who performed well can get a point and a gift.

$$GC = \left[\frac{2n\left(K_1 \bigcap K_2\right)}{n(K_1) + n(K_2)} + \frac{2m\left(K_1 \bigcap K_2\right)}{m(K_1) + m(K_2)} \right] / 2 \tag{9.1}$$

where GC represents the alignment between the collaborative learning goal and task design. $n(K_1)$ and $n(\mathrm{K}_2)$ represent the number of nodes in the target knowledge map and the knowledge map activated by task design, respectively. $n(K_1 \cap K_2)$ represents the number of common nodes both in the target knowledge map and the knowledge map activated by task design. $m(K_1)$ and $m(K_2)$ represent the number of edges of the target knowledge map and the task design activation knowledge map that is connected to the intersection of the two maps at least one end, respectively.

$m(K_1 \cap K_2)$ represents the number of edges of the intersection between the target knowledge map and the knowledge map activated by task design.

Take the second collaborative learning task (optical character recognition) as an example. Figure 9.2 shows the target knowledge map and Fig. 9.3 shows the

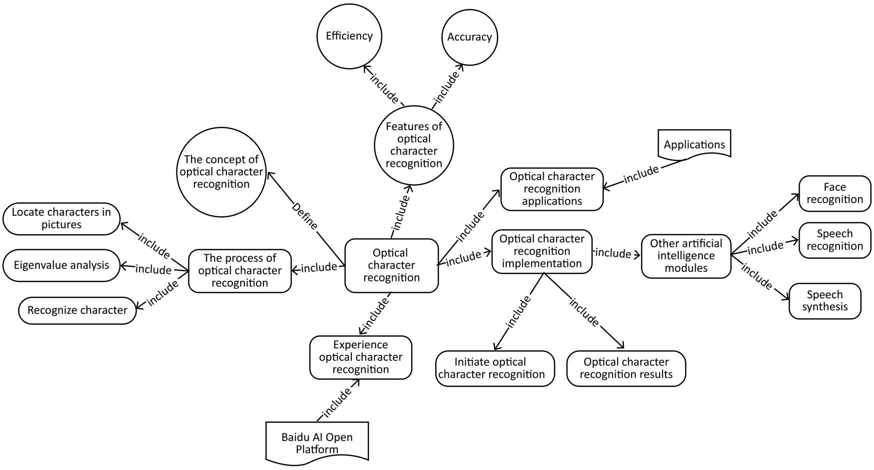

Fig. 9.2 The target knowledge map

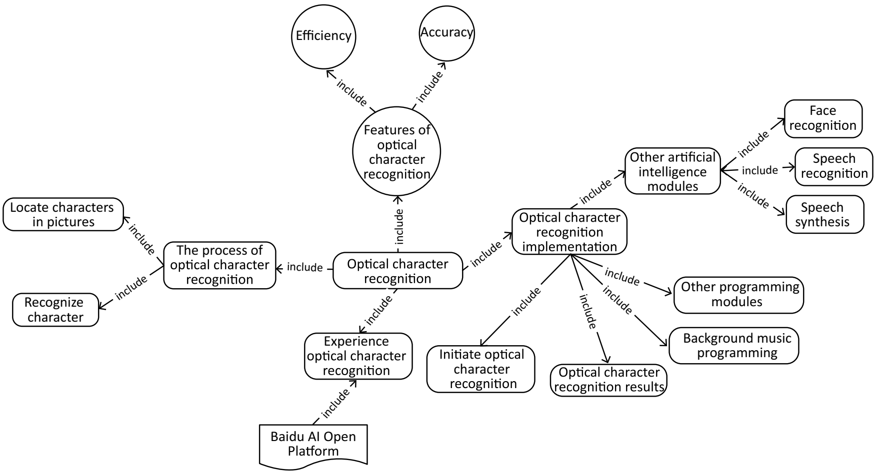

Fig. 9.3 The knowledge map activated by task design

knowledge map activated by task design. It was found that $n(K_1) = 20$, $n(K_2) = 18$, $n(K_1 \cap K_2) = 16$, $m(K_1) = 18$, $m(K_2) = 16$, and $m(K_1 \cap K_2) = 15$. Thus, $GC = \left[\frac{2*16}{20+18} + \frac{2*15}{18+16}\right]/2 = 0.862$.

Media diversity is used to represent the diversity of media tools during collaborative learning process. This study developed an indicator to measure the richness and diversity of media types based on the principles of information entropy (Shannon, 1948). Media diversity can be calculated using the formula 9.2.

$$D = -\sum_{i=1}^{N} M_i ln M_i \tag{9.2}$$

where D denotes the media diversity. M_i represents the frequency of each kind of media in collaborative learning activity design plan.

Take the second collaborative learning task as an example. There were two types of media, including texts and pictures. Among 18 target knowledge nodes, the media types of 11 knowledge nodes were text. The media types of 7 knowledge nodes were picture. Therefore, $M_1 = 0.61$, $M_2 = 0.39$, $D = 0.668$.

The adaptability of goal design represents whether or not collaborative learning goals are set for different levels of students. It can be calculated using the formula 9.3 based on Li (2012).

$$GA = 1 - \sum_{i=1}^{n} \left(\frac{N_i}{N}\right)^2 \tag{9.3}$$

where GA denotes the adaptability of the goal design. N_i denotes the number of each level of goal. N represents the total number of goals.

Take the second collaborative learning task as an example. The goal design included three levels, namely, low difficulty, medium difficulty, and high difficulty. There were 2 low-difficulty goals, 3 medium-difficulty goals, and 2 high-difficulty goals. Therefore, $N_1 = 2$, $N_2 = 3$, $N_3 = 2$, $N = 7$, $GA = 1 - [(\frac{2}{7})^2 + (\frac{3}{7})^2 + (\frac{2}{7})^2] = 0.653$.

The adaptability of task design represents whether or not collaborative learning tasks are set for different levels of students. It can be calculated using the formula 9.4 based on Li (2012).

$$TA = 1 - \sum_{i=1}^{n} \left(\frac{T_i}{T}\right)^2 \tag{9.4}$$

where TA denotes the adaptability of task design. T_i denotes the number of each level of task. T represents the total number of tasks.

Take the second collaborative learning task as an example. The task design included three levels, namely, low difficulty, medium difficulty, and high difficulty.

There were 2 low-difficulty sub-tasks, 4 medium-difficulty sub-tasks, and 2 high-difficulty sub-tasks. Therefore, $T_1 = 2$, $T_2 = 4$, $T_3 = 2$, $T = 8$, $TA = 1 - [(\frac{2}{8})^2 + (\frac{4}{8})^2 + (\frac{2}{8})^2] = 0.625$.

9.4 Results and Discussion

9.4.1 The Design Quality of Collaborative Learning Plans

This study adopted the developed four indicators to evaluate the design quality of collaborative learning. The results of four collaborative learning design plans for the first round are shown in Table 9.2. It was found that the design quality of four collaborative learning plans was low and need to be improved further. More specifically, media diversity, the adaptability of goal design, and task design need to be improved further in the second round collaborative learning.

9.4.2 The Optimization of the Design Plan

The results of the first round collaborative learning design plan indicated that the design quality needs to be improved further. Therefore, the following optimization strategies were adopted to refine the design plan of the first round collaborative learning.

Table 9.2 The results of the first round collaborative learning design plans

No.	Collaborative learning task	The alignment between collaborative learning goal and task	Media diversity	The adaptability of goal design	The adaptability of task design
1.	Make an electronic photo album	0.873	0.598	0.625	0.625
2.	Optical character recognition	0.862	0.668	0.653	0.625
3.	Develop a game of Whac-A-Mole	0.757	0.683	0.571	0.625
4.	Develop a game of feeding frenzy	0.922	0.671	0.611	0.571

First, the difficulty of collaborative learning goals was revised and added a high-difficulty goal. Second, the difficulty of task design was also modified in the second round design plan. A low-difficulty task was added and a medium-difficulty task was reduced. Third, more pictures and videos about optical character recognition were provided in the second round design plan. In addition, a collaborative writing tool was also provided for participants. Table 9.3 shows the collaborative learning design plan of the second round.

9.4.3 The Design Quality of the Second Round

Table 9.4 shows the results of design quality of the second round collaborative learning design plans. It was found that the alignment between collaborative learning goal and task design, media diversity, the adaptability of goal, and the adaptability of task improved. This results also indicated that the optimization strategies were very effective for improving design quality of collaborative learning.

9.4.4 Implications

This study has several implications for collaborative learning design. The following will illustrate in depth.

First, the design plan of collaborative learning should include the five basic elements, namely, the collaborative learning goal, collaborative learning task, interactive approaches, learning resources, and assessment methods (Zheng et al., 2020). These five elements are indispensable part of collaborative learning design plan.

Second, the collaborative learning goal should be adaptive for different levels of learners. More specifically, the collaborative learning design plan should include low-difficulty goals, medium-difficulty goals, and high-difficulty goals for different levels of learners. Learners can select different goals with different difficulties for themselves.

Third, the collaborative learning task design should match collaborative learning goal. That is to say, the knowledge and skills of collaborative learning task should embody the target knowledge and skills of collaborative learning goal. The main reason was that learners can achieve collaborative learning goal through completing collaborative learning task only when collaborative learning task design matches accurately collaborative learning goal. In addition, the collaborative learning goal should be adaptive for different levels of learners. The collaborative learning design plan should include low-difficulty tasks, medium-difficulty tasks, and high-difficulty tasks for different levels of learners.

Fourth, the representation of media within collaborative learning design plans should be diverse. For example, texts, pictures, audios, videos, and animation can be employed when designing collaborative learning plans. However, the representation

Table 9.3 The collaborative learning design plan of the second round

Dimensions	Content
Collaborative learning goals	• Low-difficulty goal: get better understanding of the concept and applications of optical character recognition. • Medium-difficulty goal: acquire the principles and characteristics of optical character recognition as well as experience optical character recognition through artificial intelligence platform. • High-difficulty goal: design an optical character recognition program to make a background music. Design an optical character recognition program integrating with face recognition or speech recognition. Develop an optical character recognition program to solve a real-life problem.
Target knowledge map	See Fig. 9.2
Collaborative learning task	• Low-difficulty sub-tasks: Do you know the concept and features of character recognition? Please compare the speed and the accuracy of character recognition by humans and machines. • Medium-difficulty sub-tasks: Please summarize the process of character recognition by humans. Do you know the process of character recognition by machine? Please experience optical character recognition through Baidu artificial intelligence platform. • High-difficulty sub-tasks: design an optical character recognition program to make a background music. Design and develop an optical character recognition program with face recognition or speech recognition to solve a problem through Simba.
Interactive approach	• The interactive strategy included brainstorm and discussion. The group members discussed and everyone expressed their opinions. • The role included the organizer, monitor, and summarizer. The organizer was responsible for facilitating the whole collaborative learning process and guiding all group members to complete the task. The monitor was responsible for criticizing group members' ideas and provided suggestions. The summarizer was responsible for summarizing the main ideas of programming and guiding group members to reflect collaborative learning process and group products.
Learning resources	Learning resources included program software Simba, Baidu artificial intelligence platform, collaborative writing tool, and questionnaire. The scaffolding included the task list, learning materials, pictures, and videos about optical character recognition.
Assessment method	The teacher evaluated group products based on the assessment criteria. The excellent group products will be demonstrated and shared with all students. The group who performed well can get a point and a gift.

Table 9.4 The results of the second round collaborative learning design plans

No.	Collaborative learning task	The alignment between collaborative learning goal and task	Media diversity	The adaptability of goal	The adaptability of task
1.	Make an electronic photo album	0.956	0.681	0.640	0.640
2.	Optical character recognition	0.897	1.049	0.656	0.656
3.	Develop a game of Whac-A-Mole	0.899	0.776	0.656	0.667
4.	Develop a game of feeding frenzy	0.970	0.769	0.656	0.625

of media mainly depends on the content of learning materials and cannot increase learners' cognitive load (Sweller et al., 2019).

Fifth, assessment method of collaborative learning should clearly indicate the assessment criteria, assessment tool, and reward and punishment mechanism. Usually, the assessment method should focus on both collaborative learning process and outcomes. Peer assessment has been validated as an effective method for collaborative learning (Zheng et al., 2018, 2020) and it can be adopted when evaluating collaborative learning process and outcomes. In addition, reflective assessment was paid more attention in recent years. For example, Lei and Chan (2018) believed that reflective assessment contributed to productive discourse and promoting meta-discourse process and knowledge advancing during collaborative learning.

9.5 Conclusions

This study proposed an innovative method to evaluate the design quality of collaborative learning plan. The four indicators were developed and validated by 4 collaborative learning tasks and 8 collaborative learning design plans. It was found that the alignment between collaborative learning goal and task design, media diversity, the adaptability of goal design, and the adaptability of task design were effective for evaluating the design quality of collaborative learning plan. In addition, it was also found that the alignment between collaborative learning goal and task design, media diversity, the adaptability of goal design, and the adaptability of task design can be improved through optimization of collaborative learning design plans.

However, there are several limitations for this study. First, only 4 collaborative learning tasks and 8 collaborative learning design plans were developed to validate the evaluation method. Future studies will design more collaborative learning design plans to validate the evaluation method and develop more indicators. Second, the learning domain in the present study was about artificial intelligence. Future studies will examine the effectiveness of this method in other learning domains.

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Chapter 10
The Study on Analyzing the Fidelity of Enactment in Computer-Supported Collaborative Learning

Abstract Computer-supported collaborative learning (CSCL) has been paid more and more attention since it contributed to twenty-first century success. In the field of CSCL, most studies focused on the effectiveness of collaborative learning environment and developed advanced technologies to support collaborative learning. Little is known that whether or not the enactment is consistent with collaborative learning design plans. Therefore, the present study sought to close this gap to analyze the fidelity of enactment in CSCL through the qualitative and quantitative analysis methods. Two cases about the applications of artificial intelligence technologies were designed, implemented, and analyzed through interactive path graphs and three alignment indicators. The results indicated that interactive path graphs and three alignment indicators were useful and effective for analyzing the fidelity of enactment. The quality of the second round collaborative learning was better than that of the first round in terms of interactive paths and fidelity of enactment. The results together with the implications for teachers and practitioners were discussed in depth.

Keywords Collaborative learning design · The fidelity of enactment · Alignment

10.1 Introduction

Collaborative learning has been a main educational goal related to twenty-first century success (Lee et al., 2014). Previous studies have revealed that collaborative learning contributed to promoting knowledge exchange (Erkens & Bodemer, 2019), social skills (Mendo-Lázaro et al., 2018), and learning performance (Fakomogbon & Bolaji, 2017). However, the effectiveness of collaborative learning cannot occur spontaneously (Wang & Mu, 2017). To be noted is that collaborative learning need to be designed elaborately ahead of enactment to achieve the desired outcomes. However, most studies on collaborative learning focused on students' learning outcomes (Abedin et al., 2012), behavioral pattern (Wang et al., 2020), lag-sequential analysis of group differences (Sun et al., 2021), implementation of interventions through

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pedagogical conversational agent (Hayashi, 2020) or CAVE automatic virtual environment (de Back et al., 2020). There is a lack of study on how to design collaborative learning as well as analysis of alignment between design and enactment.

Collaborative learning design aims to make a plan to sequence group practices (Medina & Stahl, 2020). More specifically, the goal of collaborative learning design is to create artifacts, activities, and environments to support group meaning making (Stahl et al., 2020). Generally speaking, collaborative learning design is often conducted by teachers or practitioners. The implementation of collaborative learning is conducted by students or pre-service teachers. As a teacher or designer, it is very important to understand whether or not the enactment is consistent with collaborative learning design. That is to say, the fidelity of enactment is very crucial for informing teachers or designers to know about the effects of design and optimize design. In this study, the fidelity of implementation is defined as the alignment between design and enactment. To the best of our knowledge, very few studies analyzed the fidelity of enactment. To close this research gap, this study adopted an innovative approach to analyzing the fidelity of enactment qualitatively and quantitatively in CSCL context. The main research questions focus on whether or not learners performed what was designed in CSCL. The following sections will illustrate how to analyze the fidelity of enactment through two case studies.

10.2 Literature Review

10.2.1 Collaborative Learning Design

Collaborative learning design plays a very crucial role for improving collaborative learning quality. Researchers adopted different approaches to design collaborative learning activity, including activity theory (Lewin et al., 2018), design-based research (Tissenbaum & Slotta, 2019), and design-centered research (Zheng et al., 2020). Most studies adopted design-based research or activity theory to design and implement collaborative learning. Activity theory was proposed by Vygotsky (1978) and extended by Engeström (1999). There are six elements that were included in the activity theory, namely, subject, object, tools, community, rules, and division of labor (Engeström, 1999). Activity theory has been widely used in CSCL field. For example, Saleh et al. (2020) adopted activity theory to design collaborative learning systems to support collaborative inquiry learning and understand the synergies between human and computer support. Haruzuan Mohamad Said et al. (2014) used activity theory to analyze and evaluate the outcomes of online collaborative learning. Dang et al. (2017) drew on activity theory and utilize context to shape teacher collaborative learning.

In addition, design-based research focuses on designing interventions and examining the effectiveness through iterations (Design-Based Research Collective, 2003). In the field of CSCL, many studies adopted design-based research to examine the particular intervention. For example, Li and Chu (2018) adopted design-based research method to carry out a wiki-based collaborative writing and they found that the Chinese language teachers and most of the students had positive attitudes and perceptions toward the wiki-based collaborative process writing pedagogy. Johnson et al. (2017) utilized design-based research to develop meaningful online discussion and they found that design factors (i.e., student engagement, group structures, and organization) influenced the nature and degree of deep online learning. Alharbi et al. (2018) used design-based research to develop a scripted computer-supported collaborative learning environment to support collaborative learning. In addition, design-based research was used to test the adaptation of agile principles for generating new theories of online collaborative learning (Noguera et al., 2018).

Recently, design-centered research emerged in the field of education and collaborative learning. Design-centered research (DCR) was proposed by Yang (2013) and design-centered research focuses on the design of interventions and the analysis of the alignment between design and enactment. To the best of our knowledge, very few studies designed collaborative learning activities based on design-centered research. It is also scarce to analyze the alignment between design and enactment in the field of collaborative learning. To close this gap, the present study adopted the design-centered research to analyze the fidelity of enactment of collaborative learning design qualitatively and quantitatively.

10.2.2 The Research on Alignment

Alignment is conceptualized as the degree to which expectations and assessments are in agreement with one another (Webb, 1997). Instructional alignment is conceptualized as aligning instruction with goals, objectives, content, teaching strategies, and assessment (Martin, 2011). It is very important for teachers or practitioners to align instructional content, instructional strategies, assessment methods, and implementation with instructional goals. It was found that aligned instruction was four times more effective than misaligned instruction (Cohen, 1987). It has been reported that aligned instruction also contributed to meaningful learning (Carter, 2008).

However, how to analyze instructional alignment is still a major concern. In the field of CSCL, very few studies analyze and evaluate alignment. Only Zheng et al. (2020) evaluated the alignment between online collaborative learning design and enactment for 20 collaborative learning activities focusing on social science. Therefore, it is still a lack of analyzing the alignment in natural and engineering science in CSCL context. This study sought to analyze the fidelity of implementation of a collaborative learning design plan that focused on the field of artificial intelligence. The following will illustrate the method, results, and implications in depth.

10.3 Method

10.3.1 Participants

Participants were from a junior high school in Beijing. Totally 72 students from two classes participated in this study. In order to examine the prior knowledge of the two classes, the pre-test was conducted and the results of pre-test revealed that there was no significant difference in prior knowledge between the two classes ($t = 1.101$, $p = 0.275$).

10.3.2 Procedure

The procedure of this study includes five steps. First, design the collaborative learning task. Second, conduct collaborative learning for the first round and record the whole collaborative learning process. Third, analyze the first round collaborative learning by drawing the interactive path graph and calculating the alignment between design and enactment. Fourth, revise and optimize collaborative learning design plan of the first round based on the analysis results. Fifth, conduct the second round collaborative learning and analyze the results as well as compare with alignment of the first round.

10.3.3 Analysis Methods

The analysis methods included the qualitative and quantitative analysis methods. The qualitative analysis was conducted through drawing the interactive path graph. The interactive path graph consisted of collaborative learning sub-task descriptions, the actual interactive path, the expected interactive path, and the learning engagement of each group member. Figure 10.1 shows the example of an interactive path graph. The differences between what students interact with each other during collaborative learning and what teachers expected can be clearly found. The quantitative analysis aims to calculate the alignment between design and enactment in terms of the alignment of the range of activated knowledge, the alignment of the degree of knowledge building, and the alignment of the interactive approach. The algorithm can be referred to Zheng et al. (2020).

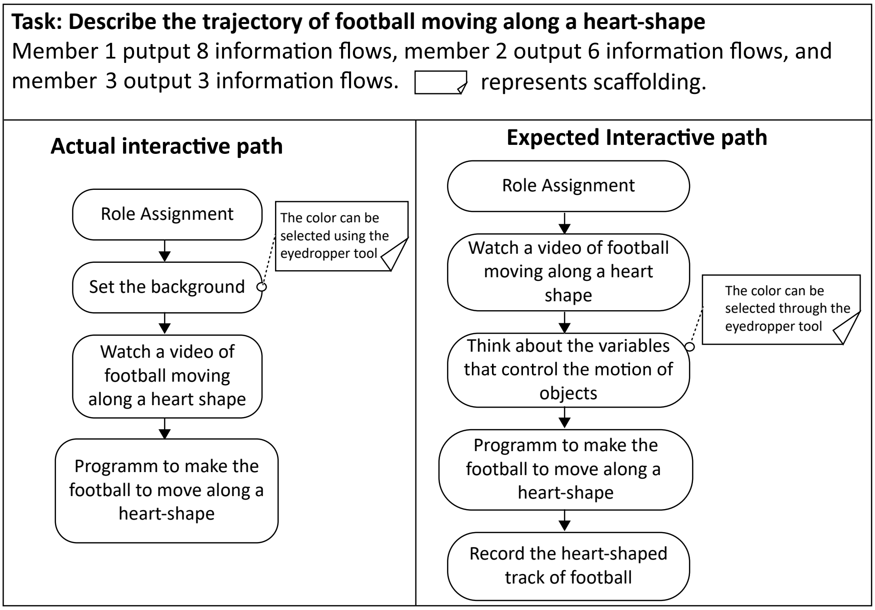

Fig. 10.1 The example of an interactive path graph

10.4 Results and Discussion

In this section, two cases about how to analyze alignment were illustrated in depth. The first case was about automatic drive and the second case was to conduct clustering through K-means algorithm. The following sections will explain one by one.

10.4.1 The First Case Study on Automatic Drive

The first case was to engage students in learning how to operate the car to run automatically. The collaborative learning task was described as follows.

XiaoMing is attending a science and technology competition. It requires to operate a car to run along the given route (the upper is triangle and the nether is square). The first sub-task was to represent how the car makes a turn, and the second sub-task was to explore how to run along the complex path. However, XiaoMing don't know how to solve this problem. Please help XiaoMing to write a program to solve the problem.

Figure 10.2 shows one groups' interactive path graph of the first round collaborative learning. It was found that the interactive path was consistent between the actual path and the expected path for the first sub-task. As to what the teacher expected, this group analyzed the characteristics when the car made a turn. Then they calculated the duration of making a turn. Finally, they wrote how to make a right angle turn

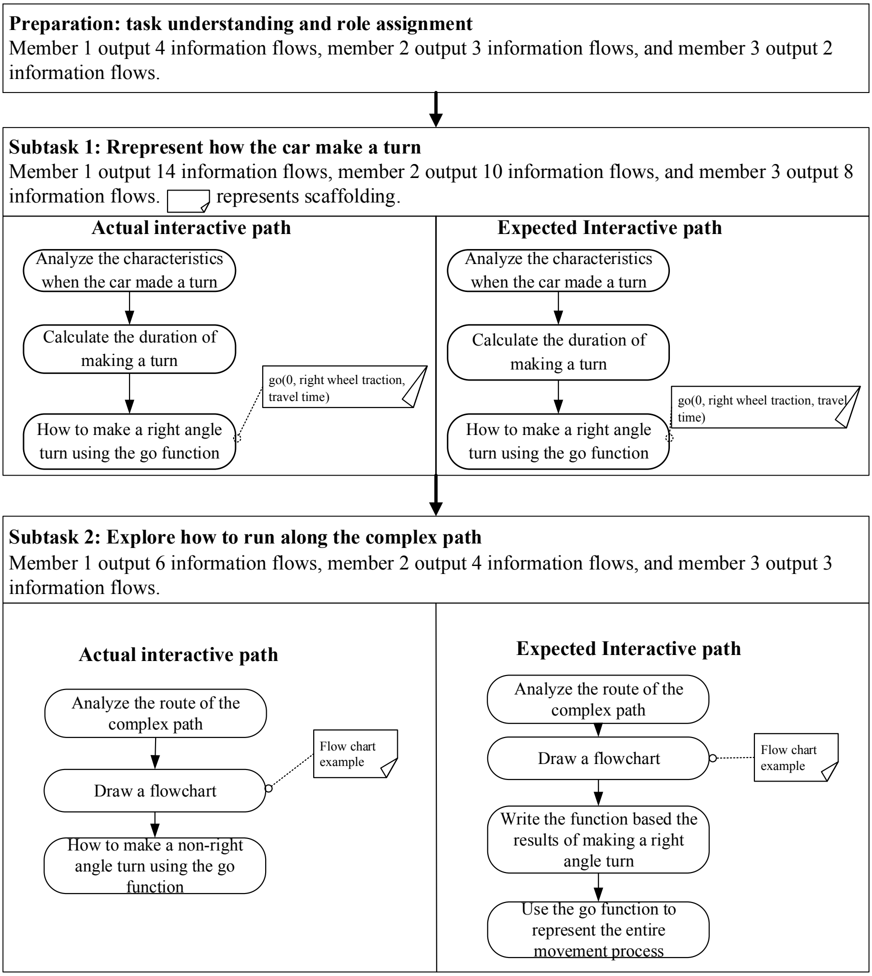

Fig. 10.2 The interactive path graph of the first round collaborative learning

using the function. However, as shown in Fig. 10.2, the actual interactive path of the second sub-task was different from the expected path. This group took lots of time to analyze the route of the complex path when completed the second sub-task. Then they drew a flow chart together. Finally, they wrote how to make a non-right angle turn using the go function for a short time. The main problem was that this group did not connect with the first sub-task and write the function based on the results of making a right-angle turn.

In addition, it was found that the first group member 1 output the most information flows, followed by the second group member. The third group member output the least information flows. The second and the third group member did not perform their responsibilities according to the requirements. Overall, this group did not achieve the expected the learning objectives. The main reason lay in two aspects. First, students did not acquire the function about how to make a turn. Second, the two sub-tasks were not related to each other and need to be improved further.

To improve the first round collaborative learning, the collaborative learning design plan was revised in terms of collaborative learning task, role assignment, and requirements. Figure 10.3 shows one groups' interactive path graph of the second round

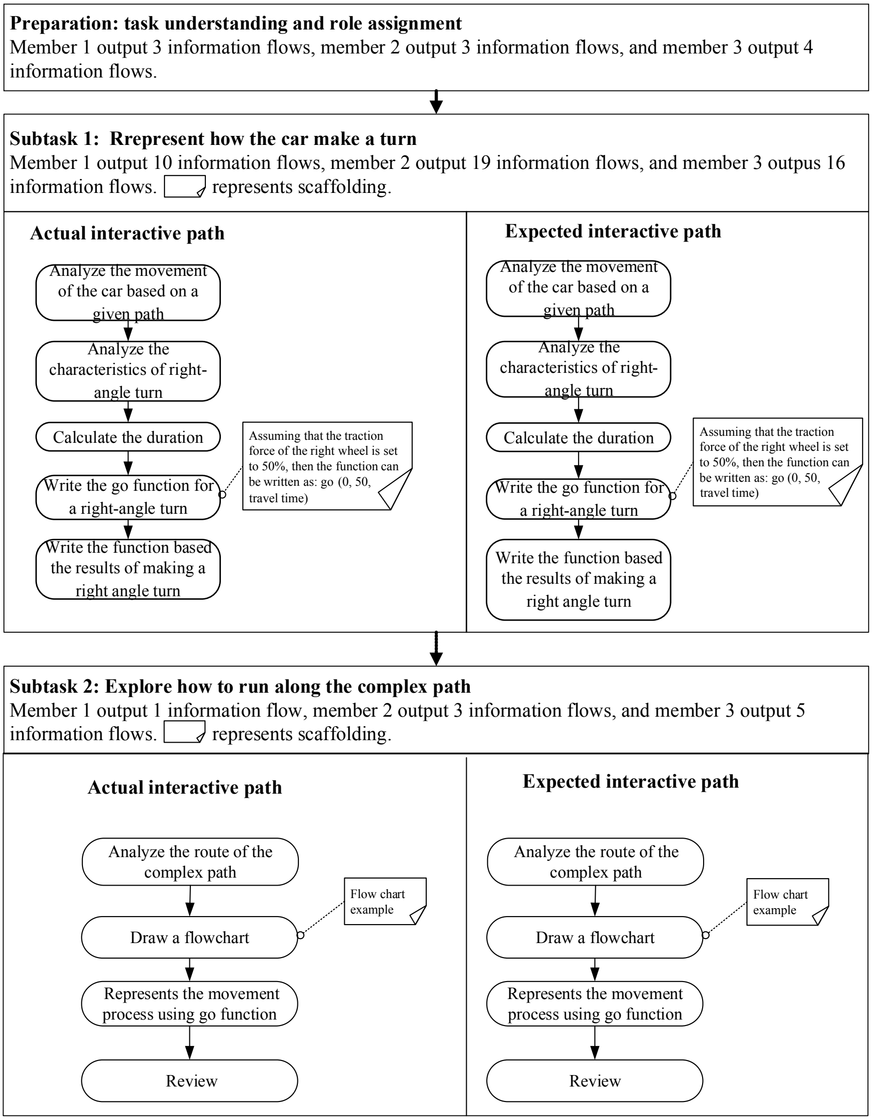

Fig. 10.3 The interactive path graph of the second round collaborative learning

collaborative learning. It was found that the actual interactive paths of the two sub-tasks were in line with the expected paths. In addition, the group members were more active and the degree of learning engagement was improved than that of the first round.

Furthermore, the quantitative analysis was conducted to calculate the alignment between design and enactment. The results indicated that the alignment of the range of activated knowledge, the alignment of the degree of knowledge building, and the alignment of the interactive approach for the first round collaborative learning were 0.737, 0.378, and 0.806, respectively. In addition, the alignment of the range of activated knowledge, the alignment of the degree of knowledge building, and the alignment of the interactive approach for the second round collaborative learning were 0.957, 0.892, and 0.917, respectively. Therefore, the alignment between design and enactment for the second round collaborative learning improved significantly after optimizing the collaborative learning plan of the first round.

10.4.2 The Second Case Study on the Classification Through K-Means

The second case was to engage students in learning how to use K-means algorithm to classify. The collaborative learning task was described as follows.

There were six students who want to participate in physical exercise. They want to divide into different groups to do daily physical exercise. The accurate location of everyone's home address has been provided by the teacher. Would you like to help these six students to divide into groups using K-means algorithm?

As shown in Fig. 10.4, it was found that the actual interactive paths of the two sub-tasks were different from the expected paths. For the first sub-task, the group members only demonstrated the initial classification results. For the second sub-task, the group members did not complete at all. The main reason was that the group members did not acquire the principle of K-means algorithm. They took lots of time to calculate the distance between the group leader and group members, thus they had no time to complete the second sub-task.

To improve the first round collaborative learning, the collaborative learning design plan was revised in terms of collaborative learning task, role assignment, and providing more cognitive scaffolding. Figure 10.5 shows one groups' interactive path graph of the second round collaborative learning. It was found that the actual interactive paths of the second sub-task were in line with the expected paths. But the actual interactive paths of the first sub-task were a little bit different from the expected paths. The group members demonstrated the initial classification results, they did not select the new group leader and calculate the distance between the new group leader and each group member. They did not compare the difference between the two classification results. The main reason was that the group members did not acquire how to calculate the central point of the clustering. Overall, the second round

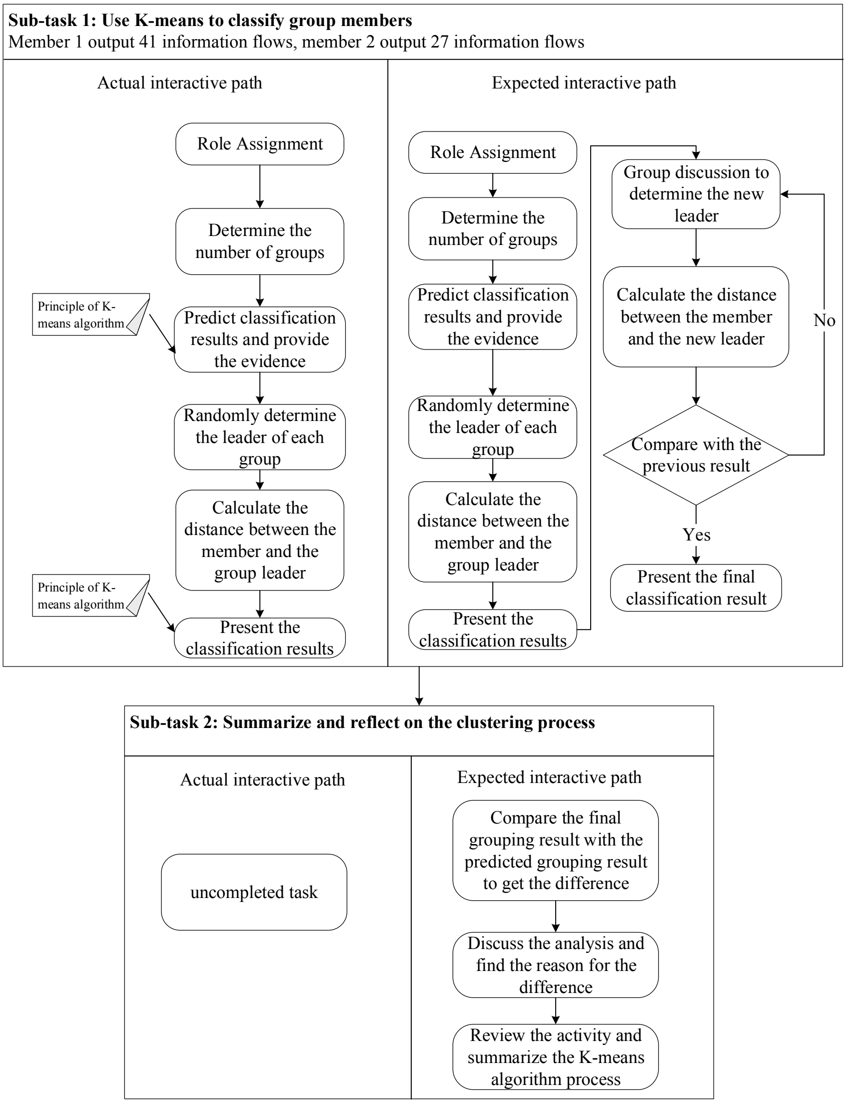

Fig. 10.4 The interactive path graph of the first round collaborative learning

collaborative learning was better than the first round collaborative learning. In addition, the group members were more active and the degree of learning engagement was improved than that of the first round.

Furthermore, the quantitative analysis was conducted to calculate the alignment between design and enactment. The results indicated that the alignment of the range of activated knowledge, the alignment of the degree of knowledge building, and the alignment of the interactive approach for the first round collaborative learning

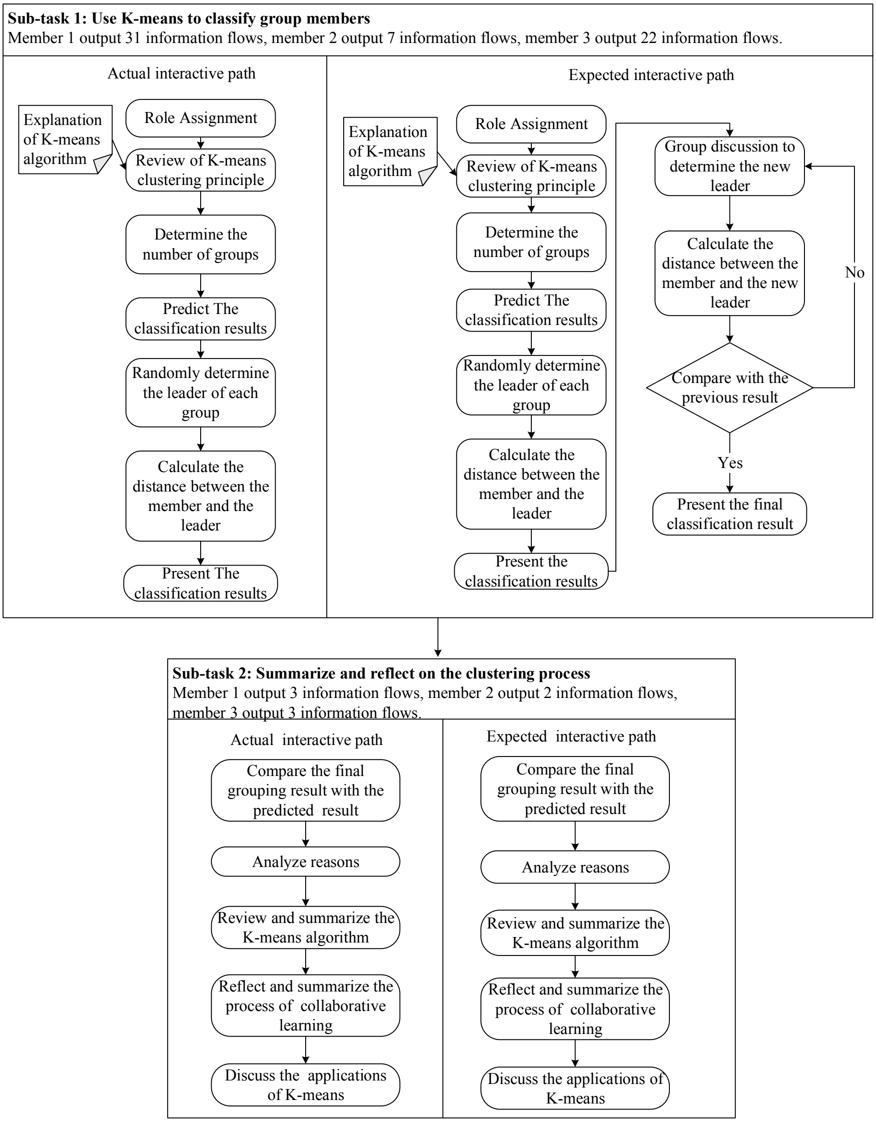

Fig. 10.5 The interactive path graph of the second round collaborative learning

were 0.870, 0.647, and 0.708, respectively. In addition, the alignment of the range of activated knowledge, the alignment of the degree of knowledge building, and the alignment of the interactive approach for the second round collaborative learning were 0.919, 0.920, and 0.917, respectively. Therefore, the alignment between design and enactment for the second round collaborative learning improved significantly through optimizing the collaborative learning plan of the first round.

10.4.3 Implications

This study had several implications of designing and implementing collaborative learning for teachers and practitioners.

First, this study highlighted the importance of design and refined collaborative learning design based on the analysis results of alignment. Reigeluth (2013) stated that instructional design focus on what the instruction should be like. Instructional design in CSCL includes designing collaborative learning objectives, tasks, learning environment and resources, interactive strategies, and assessment methods. It should be noted that the design of tasks, learning environment and resources, interactive strategies, and assessment methods need to match with collaborative learning objectives.

Second, collaborative learning task design is very crucial for successful collaborative learning. Collaborative learning tasks should clearly indicate the context, problems, outcomes, and other requirements such as deadline or format, and so on. Previous studies revealed that learning context is helpful for getting better understanding of tasks (Apps et al., 2019; Oshige, 2009). In addition, it is suggested that an open-end problem-solving task should be designed to engage learners in collaboratively completing the task. Moreover, learning outcomes and group products should be indicated when design collaborative learning task. To stimulate learners' motivations, collaborative learning tasks should be from real-life world and link to prior knowledge.

Third, role assignment is important for implementing collaborative learning. However, the responsibilities of each role should be clearly indicated when designing the task. Otherwise, it will result in social loafing and free riding. Social loafing and free riding had the similar features, in that each describes a group member who did not provide the maximum effort during collaboration (Kidwell & Bennett, 1993). In order to minimize social loafing and free riding, teachers or practitioners should clarify roles and responsibilities, emphasize the importance of teamwork, and ensure that individuals feel they are valuable for achieving the end goal (Piezon & Donaldson, 2005).

Fourth, it is also recommended to provide cognitive and metacognitive scaffolding for learners to review what they have learned, link prior knowledge with new information, activate more target knowledge, and implement collaborative learning strategically. Previous studies revealed that cognitive scaffolding was helpful for improving collaborative problem-solving abilities and diverse cognitive process (Lin et al., 2020). It was also found that CSCL scripts improved learning outcomes, leading to a positive effect on collaboration skills and a small effect on domain knowledge (Vogel et al., 2017). Furthermore, group metacognitive scaffolding contributed to the improvement of group metacognitive behaviors and group performance (Zheng et al., 2019).

Fifth, the analysis of alignment had significant values for improving collaborative learning quality. The three indicators about the alignment between design and enactment are very effective for examining the consistence between what group members actually done and what the teacher expected. Whether or not the design elements have been enacted can also be clearly found after calculating the alignment. Therefore, it is suggested that teachers or researchers should analyze the alignment between CSCL design and enactment to improve interventions and design quality.

Sixth, this study adopted an interactive path graph to analyze the alignment between collaborative learning design and enactment. The interactive path graph is very helpful for qualitatively analyzing the alignment between the actual interactive paths and the expected interactive paths. The interactive path graph contributed to getting better understanding of the reasons of misalignment as well as design deficiency. The interactive path graph is also very useful for refining and optimizing collaborative learning design plan.

10.5 Conclusions

This study analyzed the alignment between collaborative learning design and enactment through two cases. Both the qualitative and quantitative analysis methods were adopted to quantify and identify the alignment through three indicators and interactive path graph. The results indicated that the misalignment can be clearly identified through three indicators and interactive path graphs. The results further informed the design deficiency to promote the optimization of collaborative learning. The second round of collaborative learning for two cases also demonstrated that the alignment was improved compared with the first round collaborative learning.

This study had several limitations. First, only two cases were analyzed to identify the alignment in the present study. Future studies will implement more collaborative learning activities to analyze the alignment in depth. Second, the learning domain of the two cases focused on artificial intelligence for junior school students. Future studies will design and implement collaborative learning activities in other learning domains. Third, the duration of each collaborative learning activity was short since the school hour duration was limited in a junior school. Future study will implement collaborative learning activity for a long time to conduct a longitudinal study.

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Chapter 11
Optimize CSCL Activities Based on a Data-Driven Approach

Abstract Computer-supported collaborative learning (CSCL) has been widely used in the field of education. Computer-supported collaborative learning plays a very crucial role for improving learning performance, social interaction skills, problem-solving abilities, and knowledge building. However, most studies focus on implementing collaborative learning activities based on personal and subjective experiences. Previous studies seldom examine how to optimize collaborative learning activities based on a data-driven approach. This study aims to bridge this gap to propose how to optimize collaborative learning activities as well as evaluate the effectiveness of optimization strategies. Totally 72 junior school students participated this study and completed 7 collaborative learning tasks. For each collaborative learning task, two rounds of collaborative learning were implemented and recorded for analysis. The results indicated that the proposed 17 optimization strategies were very effective for improving the design quality of collaborative learning, the alignment between design and enactment, collaborative knowledge building level, and group products quality. The results and implications for teachers and practitioners are also discussed in depth.

Keywords Collaborative learning · Data-driven approach · Optimization strategy

11.1 Introduction

Collaborative learning is conceptualized as an instructional strategy that students learn together to maximize their own and peers' learning (Johnson et al., 1991). Computer-supported collaborative learning (CSCL) is characterized as the sharing and construction of knowledge through the use of computers (Stahl et al., 2006). CSCL was grounded in the theory of socio-cultural that focused on enculturation through participation in the activities to learn norms, values, knowledge, and skills (Brown et al., 1989; White, 2018). It was found that CSCL contributed to improving learning performance (Shin et al., 2020; Zheng et al., 2017) and higher order skills (Cheng et al., 2020; Fu & Hwang, 2018).

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In the field of CSCL, there are many different research foci. For example, some researchers focused on developing group awareness tools (Kwon, 2019; Wang et al., 2019) or building computer-supported collaborative learning environment (Karno & Hatcher, 2020) to facilitate collaborative learning. Some researchers centered on analyzing social interaction features and patterns through social network analysis method (Lee & Bonk, 2016; Wagner & González-Howard, 2018; Saqr et al., 2020). Some researchers promoted knowledge building in different learning domains through knowledge forum or cross-community interaction (Scardamalia & Bereiter, 1994; Stahl, 2000; Zhang et al., 2020). In addition, it was found that collaborative learning need to be designed and orchestrated through scripts (Fischer et al., 2013; Radkowitsch et al., 2020; Ramirez & Monterola, 2019), cognitive scaffolding (Vogel et al., 2017), or metacognitive scaffolding (Zheng et al., 2019). However, very few studies focus on how to optimize collaborative learning from the perspective of a data-driven approach. This study aims to close the gap to examine how to optimize collaborative learning and evaluate the effectiveness of the optimization strategies through an empirical study. The following sections will illustrate methodology, results, and conclusions in depth after reviewing previous studies.

11.2 Literature Review

11.2.1 Optimization of Collaborative Learning Activity

In the field of CSCL, most studies adopted a design-based research to refine collaborative learning activity in terms of a collaboration tool, pedagogical model, and professional development experience. For example, Hoadley (2002) adopted design-based research to refine a discussion tool to create an environment of inquiry and collaboration. This tool was evolved from a general discussion tool to an Internet-based science environment and evolved to support offline and online classroom projects through the use of social cue. In addition, Leinonen et al. (2016) took a design-based research to explore how to use mobile apps to support reflection during collaborative learning. They found that there was a potential to promote learners' reflection through mobile apps for audio-visual recording. Furthermore, Alvarez et al. (2011) employed a design-based research to develop a mobile CSCL environment to facilitate an integrative learning design framework and collaborative learning. They found that this framework was positive toward creating pedagogical strategies for MCSCL activity. Moreover, Ketelhut et al. (2019) used a design-based research to examine an extended professional collaborative learning experience to embed computational thinking for teachers. They found that resource sharing, discussion, and hands on experiences were helpful in facilitating the development of computational thinking. Lyons et al. (2021) adopted two cycles of design-based research to develop a web-based tool to help learners overcome challenges in group work.

Although the design-based research approach is helpful for refining the interventions through the iterative cycles, there are many deficiencies with design-based research. For example, it is very difficult to validate the effectiveness of interventions (Zheng & Yang, 2014) and replicate the design-based research as well as generalize the results (Barab & Squire, 2004). That is to say, the optimization strategies proposed by design-based research were doubtful and lack of enough evidence. In addition, previous studies mainly proposed the optimization strategies based on personal experience or subjective perceptions (Damşa & Ludvigsen, 2016; Kalir, 2018). It is lack of objective evidence, and particularly, the data-driven optimization. Therefore, there is a research gap in how to optimize collaborative learning activity based on data-driven approach.

11.2.2 Data-Driven Approach in Education

Data-driven approach has been widely used to form groups, predict, decision making, and design in the field of education. The data-driven research approach starts from large amounts of data to understand the real-world, extract new knowledge, and solve problems through building models (Kulin et al., 2016). For example, Rubens et al. (2009) developed a data-driven group formation model to automatically form collaborative learning groups through extracting information about learning materials and learners. Cen et al. (2016) made a pioneering effort to predict group performance through the data-driven learning model to gain an objective and quantitative insight into why collaboration is effective. In addition, a data-driven approach can be adopted to make decision and design products. Data-driven decision making refers to analyzing existing data sources to innovate teaching, curricula, and school performance (Schildkamp & Kuiper, 2010). For example, Schildkamp and Kuiper (2010) stated that teachers can use classroom-level data to make instructional decisions, and school leaders can use school-level data to make policy decisions. Moreover, Bahirat et al. (2018) applied a data-driven approach to develop Internet-of-Things (IoT) devices based on an existing dataset. Some researchers adopted a data-driven approach to conduct learning design. Niles-Hofmann (2017) believed that data-driven learning design was to gain design insights, make informed strategies, build or adjust content based on learners' data.

11.3 Method

11.3.1 CSCL Tasks

This study designed 7 collaborative learning tasks to explore how to optimize collaborative learning design and enactment. Table 11.1 shows the details about the 7 collaborative learning tasks. The topics of seven collaborative learning tasks were about natural language processing, a knowledge graph, man-machine boxing match, programming using KNN algorithm, decision tree, labyrinth adventure, and image recognition.

Table 11.1 The list of seven collaborative learning tasks

No.	Tasks	Introduction
1	Natural language processing	This task aims to engage learners in getting better understanding of the concepts and principles of natural language processing as well as experience the applications of natural language processing through artificial intelligence platform.
2	Knowledge graphs	The purpose of this task is to get better understanding of the principles and applications of knowledge graphs. Learners should construct knowledge graphs and conduct knowledge reasoning.
3	Man-machine boxing match	This task aims to engage learners in writing a program about man-machine boxing match through artificial intelligence technologies.
4	Programming using KNN	This task aims to help students to understand and apply KNN to write a program about balls categorization.
5	Decision tree	This task aims to help learners to acquire the concepts, principles, and applications of decision tree as well as to construct a decision tree based on the given data.
6	Labyrinth adventure	The purpose of this task is to engage learners in writing a program about labyrinth adventure.
7	Image recognition	This task aims to help students to acquire the techniques about image recognition and design a plan to solve a real-life problem using image recognition.

11.3.2 Participants

The participants were from a junior school in Beijing. Totally 72 students from two classes participated in this study. One class with 34 students participated in the first round collaborative learning and one class with 38 students participated in the second round collaborative learning. The pre-test about artificial intelligence was conducted to examine the prior knowledge of two classes. The results of pre-test indicated that there was no significant difference in prior knowledge between the two classes ($t = 1.101$, $p = 0.275$).

11.3.3 Procedure

The procedure of optimizing collaborative learning activity included four steps. First, design and implement the first round collaborative learning activity. All of the participants of two classes were divided into different groups of three students who conducted face-to-face collaborative learning with the support of computers. Second, analyze and evaluate the design quality, process, and outcomes of collaborative learning. Third, make optimization strategies based on the analysis results and refine the design plan. Fourth, implement the second round collaborative learning activity and validate the effectiveness of optimization strategies.

11.3.4 An Example

In this section, we will take one collaborative learning activity as an example to illustrate how to evaluate and optimize collaborative learning activity in detail. The topic of this collaborative learning activity was about small ball classification based on KNN (K-Nearest Neighbor) algorithm.

Table 11.2 shows the design plan of the first round collaborative learning activity. Based on this design plan, the first round collaborative learning was implemented. The researcher recorded the whole collaborative learning process through videos. This study developed four types of indicators to evaluate collaborative learning design and enactment, including the design quality, the alignment between design and enactment, collaborative knowledge building level, and collaborative learning outcomes. The design quality can be evaluated in terms of the alignment between collaborative learning objectives and task design, media diversity, the adaptability of goal design, and the adaptability of task design. The algorithm can be referred to the previous chapter. The alignment between design and enactment can be evaluated in terms of the alignment of the range of activated knowledge, the alignment of the degree of knowledge building, and the alignment of the interactive approach. The algorithm can be referred to Zheng et al. (2020). The collaborative knowledge-building level can be evaluated in terms of the activation quantity, knowledge elaboration, and knowledge convergence. The algorithm can be referred to Zheng (2017). The group product quality can be evaluated based on the pre-defined criterion.

According to the results of the first round collaborative learning, it was found that the alignment between collaborative learning goal and task design achieved 0.882. Some target knowledge was not activated in the task design plan. The media diversity was 0.681. The main reason lay in that there were only texts and pictures for task design. The adaptability of goal design was only 0.611 because it was lack of low-difficulty goal and high-difficulty goal. The adaptability of task design only achieved 0.612 because it was lack of high-difficulty task. In addition, it was found that the alignment of the range of activated knowledge, the alignment of the degree of knowledge building, and the alignment of the interactive approach achieved 0.848,

Table 11.2 The design plan of the first round collaborative learning

Dimensions	Descriptions
Collaborative learning goals	• Low-difficulty goal: understanding the concept of K value. • Medium-difficulty goal: understanding the role assignment of programming, speech recognition embedding, and initializing routine. • High-difficulty goal: acquiring the concept and principle of KNN.
Collaborative learning tasks	Context: The teacher told Xiaoming to categorize the balls into red balls and blue balls. However, Xiaoming found a yellow ball and decided to throw the yellow ball into red balls or blue balls. If the yellow ball was near to red ball, then it will be categorized into red ball. Otherwise, it will be categorized into blue ball. • Low-difficulty sub-tasks: complete the program about red ball. • Medium-difficulty sub-tasks: calculate the distance among the yellow ball, red ball, and blue ball. • High-difficulty sub-tasks: Please discuss the principles and applications of KNN.
Interactive approach	The interactive strategy included brainstorm and discussion. The group members discussed face-to-face and everyone expressed their opinions. The role included the organizer, monitor, and summarizer. The organizer was responsible for facilitating the whole collaborative learning process and guiding all group members to complete the task. The monitor was responsible for monitoring the whole collaborative learning process. The summarizer was responsible for summarizing the main ideas and guiding group members to reflect collaborative learning process and group products.
Learning resources	Learning resources included program software Simba, and a collaborative writing tool. The scaffolding included the task list and learning materials about KNN algorithm.
Assessment method	The teacher evaluated group products based on the assessment criteria. The group who performed well can get a point and a gift.

0.600, and 0.708, respectively. Part of target knowledge was not activated and many were off-topic information output. Furthermore, the results also indicated that the level of collaborative knowledge building was low and need to be improved further. The quality of group product need to be improved in the second round collaborative learning. Therefore, the following optimization strategies were adopted to refine collaborative learning design and enactment.

First, revise the collaborative learning design plan including task design, goal design, and media representation format.

Second, provide more learning resources and scaffolding about prior knowledge to help learners to link prior knowledge and new information.

Third, specify the responsibilities of each role and add the reminder about how to collaborate and complete tasks.

Fourth, propose more questions to motivate learners to think over and provide shared space to promote knowledge convergence.

Fifth, specify the criteria about group products and reward method. Share the group products with peers and conduct peer assessment.

Table 11.3 shows the results of 11 indicators for the first and the second round collaborative learning. It was found that all of indicators of the second round collaborative learning were higher than that of the first round collaborative learning. These results also indicated that the optimization strategies were very effective for improving collaborative learning design quality and enactment.

Table 11.3 The results about 11 indicators of the collaborative learning task (small ball classification)

First-level indicators	Second-level indicators	The first round	The second round
The collaborative learning design quality	The alignment between goal and task design	0.882	0.937
	The diversity of media	0.681	0.762
	The adaptability of goal design	0.611	0.656
	The adaptability of task design	0.612	0.653
The alignment between design and enactment	The alignment of the range of activated knowledge	0.848	0.979
	The alignment of the degree of knowledge building	0.600	0.935
	The alignment of the interactive approach	0.708	0.917
Collaborative knowledge building level	The quantity of activation	35.383	86.922
	Knowledge elaboration	51.110	112.432
	Knowledge convergence	20.768	51.403
Collaborative learning outcomes	The group product	90	94

11.4 Results and Discussion

11.4.1 The Optimization Strategies

The seven collaborative learning tasks were completed through the first second round collaborative learning. Then all of data were analyzed based on the aforementioned 11 indicators. The researcher reflected the reasons why the values of these indicators were lower than what we expected. Finally, the following optimization strategies were proposed to refine the second round collaborative learning (see Table 11.4).

Table 11.4 The proposed optimization strategies

First-level indicators	Second-level indicators	Optimization strategies
The collaborative learning design quality	The alignment between goal and task design	• Optimizing task design through adding learning context and task requirements. • Activate more target knowledge when design the collaborative learning tasks.
	The diversity of media	Provide more learning materials including pictures, audio, video, and animation.
	The adaptability of goal and task	• Keep a balance among the goals of different difficulty. • Keep a balance among the tasks of different difficulty.
The alignment between design and enactment	The alignment of the range of activated knowledge	• Focus on the inactivated knowledge during collaborative learning. • Provide cognitive scaffolding for inactivated knowledge.
	The alignment of the degree of knowledge building	• Focus on the missing and wrong proposition chains. • Provide scaffolding to link prior knowledge and new information.
	The alignment of the interactive approach	• Add the reminder about collaboration strategies. • Specify the responsibilities of each role.
Collaborative knowledge building level	The quantity of activation	Provide cognitive, metacognitive scaffolding.
	Knowledge elaboration	Propose more questions to guide students to promote cognition elaboration.
	Knowledge convergence	Provide the shared collaborative learning space to promote knowledge convergence.
Collaborative learning outcomes	The group product	• Provide personalized guidance. • Specify the criterion and demonstrate the excellent group products. • Specify the reward and punishment rules.

11.4.2 *The Effectiveness of the Optimization Strategies*

In order to examine the effectiveness of the optimization strategies, the 11 indicators of two round were calculated to compare the differences. Table 11.5 shows the results of collaborative learning design quality for the two round collaborative learning. It was found that there were significant differences in the alignment between goal and task design ($t = 4.502$, $p = 0.004$), the diversity of media ($t = 5.193$, $p = 0.002$), the adaptability of goal ($t = 3.608$, $p = 0.011$), and the adaptability of task ($t = 3.382$, $p = 0.015$) between the first and second round of collaborative learning.

Table 11.5 The results of collaborative learning design quality

No.	Tasks	The alignment between goal and task design		The diversity of media		The adaptability of goal		The adaptability of task	
		1st round	2nd round	1st round	2nd round	1st round	2nd round	1st round	2nd round
1	Natural language processing	0.666	0.819	0.637	0.983	0.653	0.656	0.611	0.656
2	Knowledge graph	0.781	0.878	0.483	0.736	0.571	0.642	0.494	0.653
3	Man-machine boxing match	0.858	0.923	0.554	0.640	0.560	0.640	0.620	0.653
4	Programming using KNN	0.882	0.937	0.681	0.762	0.611	0.656	0.612	0.653
5	Decision tree	0.796	0.861	0.685	0.898	0.612	0.611	0.611	0.640
6	Labyrinth adventure	0.898	0.931	0.637	0.769	0.560	0.653	0.611	0.661
7	Image recognition	0.494	0.527	0.637	0.901	0.560	0.653	0.594	0.642

Table 11.6 The results of the alignment between design and enactment

No.	Tasks	Group	The alignment of the range of activated knowledge		The alignment of the degree of knowledge building		The alignment of the interactive approach	
			1st round	2nd round	1st round	2nd round	1st round	2nd round
1	Natural language processing	Group 1	0.645	0.667	0.167	0.244	0.708	0.917
		Group 2	0.800	0.800	0.333	0.556	0.750	0.847
2	Knowledge graph	Group 1	0.609	0.667	0.143	0.200	0.667	0.806
		Group 2	0.720	0.909	0.190	0.667	0.708	0.875
3	Man-machine boxing match	Group 1	0.731	0.882	0.333	0.757	0.667	0.764
		Group 2	0.712	0.853	0.549	0.733	0.833	0.875
4	Programming using KNN	Group 1	0.643	0.829	0.160	0.548	0.708	0.806
		Group 2	0.848	0.979	0.600	0.935	0.708	0.917
5	Decision tree	Group 1	0.741	0.889	0.538	0.692	0.750	0.806
		Group 2	0.720	0.919	0.200	0.769	0.708	0.806
6	Labyrinth adventure	Group 1	0.906	0.828	0.875	0.600	0.690	0.794
		Group 2	0.863	0.912	0.792	0.895	0.690	0.905
7	Image recognition	Group 1	0.833	0.813	0.704	0.688	0.792	0.847
		Group 2	0.833	0.941	0.704	0.871	0.708	0.958

Table 11.6 shows the results of the alignment between design and enactment for the two round collaborative learning. The results also indicated that there were significant differences in the alignment of the range of activated knowledge (t = 3.946, p = 0.002), the alignment of the degree of knowledge building (t = 3.460, p = 0.004), and the alignment of the interactive approach (t = 7.266, p = 0.000) between the first and second round of collaborative learning.

Table 11.7 demonstrates the results of collaborative knowledge building for the two-round collaborative learning. The findings also revealed that there were significant differences in the activation quantity (t = 7.002, p = 0.000), knowledge elaboration, and knowledge convergence (t = 11.005, p = 0.000), the alignment of the degree of knowledge building, and the alignment of the interactive approach (t = 4.995, p = 0.000) between the first and second round of collaborative learning.

Table 11.8 shows the results of group products for the two-round collaborative learning. It was also found that there were significant differences in the quality of group products between the first and second round of collaborative learning (t = 4.286, p = 0.001).

Table 11.7 The results of collaborative knowledge building

No.	Tasks	Group	The quantity of activation		Knowledge elaboration		Knowledge convergence	
			1st round	2nd round	1st round	2nd round	1st round	2nd round
1	Natural language processing	Group 1	30.798	45.498	38.225	73.798	20.552	25.902
		Group 2	42.830	62.416	69.812	101.472	23.706	31.223
2	Knowledge graph	Group 1	28.055	57.557	35.836	72.401	21.716	50.066
		Group 2	32.617	71.193	46.044	109.575	15.729	33.623
3	Man-machine boxing match	Group 1	80.801	137.856	241.142	278.713	25.926	60.835
		Group 2	103.779	123.552	286.741	332.886	32.466	78.609
4	Programming using KNN	Group 1	26.695	60.399	44.545	70.878	20.427	32.563
		Group 2	35.383	86.922	51.110	112.432	20.768	51.403
5	Decision tree	Group 1	42.640	49.543	64.115	89.397	19.137	34.374
		Group 2	31.609	53.760	58.417	84.089	9.533	30.005
6	Labyrinth adventure	Group 1	91.110	107.475	181.951	226.319	41.777	83.289
		Group 2	88.278	109.071	180.477	222.955	38.850	32.240
7	Image recognition	Group 1	32.482	48.930	37.431	67.766	14.623	29.682
		Group 2	27.286	53.421	38.141	102.169	10.302	19.215

Table 11.8 The results of group products

No.	Tasks	Group	1st round	2nd round
1	Natural language processing	Group 1	86	88
		Group 2	92	90
2	Knowledge graph	Group 1	85	87
		Group 2	84	94
3	Man-machine boxing match	Group 1	91	94
		Group 2	87	95
4	Programming using KNN	Group 1	89	96
		Group 2	90	94
5	Decision tree	Group 1	87	93
		Group 2	76	90
6	Labyrinth adventure	Group 1	89	93
		Group 2	91	92
7	Image recognition	Group 1	92	93
		Group 2	88	96

11.4.3 Interview Results

In order to get better understanding of learners' perceptions of CSCL and the optimization strategies, the five students from the class two were randomly selected to conduct semi-structured interview. After analyzing students' responses, it was found that students generally held five points of view about the collaborative learning strategies.

First, all of the interviewees believed that CSCL is a very effective strategy for solving the complex problems. Group members monitored, reminded, and helped each other to improve the learning efficiency significantly. For example, S1 believed that "We together to work out solutions about how to write a program about categorization balls. I really cannot finish it if I complete this task alone."

Second, they believed that providing scaffolding was very helpful for understanding the target knowledge map and complete the tasks. For example, S2 told us that "The cognitive scaffolding such as questions, reminders, and learning materials are very useful for us to complete the tasks on time." In addition, S4 believed that "The metacognitive scaffolding such as the task list and the strategies about how to complete the tasks are very helpful for our group."

Third, the interviewees also believed that adding the context about the collaborative learning tasks and task requirements are beneficial to get a better understanding of the problems and complete collaborative learning tasks. For example, S5 believed that "Initially, I really don't understand the problems. Later, the task context helped me to understand the problems."

Fourth, the use of the shared collaboration space was beneficial to improve collaborative learning efficacy. For example, S3 believed that "I like the collaborative writing tool that can help our group members to edit the document collaboratively. It is really promising."

Fifth, the reflective assessment was also a promising strategy for improving the collaborative learning effectiveness. For example, S2 stated that "Our group members reflected the whole collaborative learning process and outcomes to refine our group products. We all learned from mistakes after reflections."

11.4.4 Implications

The present study had several implications for researchers, teachers, and practitioners. First, researchers can adopt a data-driven approach to collect and analyze multiple sources and multimodal data during collaborative learning to shed light on how collaborative learning occur, evolve, and develop. The analysis results are very valuable for identifying at-risk groups (Kinshuk, 2016), evaluating team collaboration (Barmaki & Guo, 2020), improving learning experiences during peer feedback (Er et al., 2020), improving collaborative learning design (Han et al., 2021), and providing insights into optimizing collaborative learning.

Second, it is recommended that teachers and practitioners need to design collaborative learning elaborately, including collaborative learning tasks, interactive strategies, learning environment, and assessment methods. In addition, scripts, cognitive scaffolding, metacognitive scaffolding, emotional scaffolding, and motivational scaffolding are very helpful for facilitating collaborative learning (Feidakis, 2011; Järvelä, 2011; Lin, 2020; Lin et al., 2020; Roll et al., 2011; Shin et al., 2020; Zheng et al., 2019). Teachers and practitioners need to design and develop adaptive scripts or scaffolding to improve collaborative learning performance.

Third, it is suggested that teachers and practitioners should optimize collaborative learning based on a data-driven approach. The present study indicated that collaborative learning objectives, tasks, learning materials, learning environment, scaffolding, interactive strategies, and assessment methods can be optimized to promote collaborative learning design quality, collaborative knowledge building level, the alignment between design and enactment, and collaborative learning outcomes. In addition, optimization of collaborative learning is very helpful for promoting teacher professional development since teachers need to develop technological knowledge to optimize collaborative learning.

11.5 Conclusions

This study proposed 17 optimization strategies to refine seven collaborative learning activities for junior school students. This study also developed 11 indicators to evaluate the effectiveness of optimization strategies. The findings revealed that these optimization strategies significantly improved the design quality of collaborative learning, the alignment between design and enactment, collaborative knowledge building level, and group products quality. The interview results also validated that the optimization strategies were really effective for improving collaborative learning quality and efficiency.

However, this study was constrained by several limitations. First, the collaborative learning tasks were only related to artificial intelligence for junior school students. Therefore, cautions should be made when generalizing the results. Future studies will design and implement collaborative learning in other learning domains. Second, participants were from a junior school in Beijing. The sample size was small in the present study. Future study will expand the sample size to conduct collaborative learning. Third, this study proposed 11 indicators to evaluate the effectiveness of optimization strategies. Future studies will develop more indicators from other lens to evaluate the effectiveness of optimization strategies.

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