# How Roles in Collaboration Respond to the Exchange of Device-Student Ratio Under the Impact of External Scripts?

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**ABSTRACT:** In science classrooms, technology affordance varies depending on device-student ratios (DSR) and the ways virtual manipulatives on mobile devices are used. Additionally, external scripts (ES) are widely used to promote effective group interaction in collaborative learning. Therefore, this research explored the influence of DSR and ES on collaborative inquiry learning. This research adopted a counterbalanced design between two rounds of experiments. A total of 128 students (including 11 dropouts) from four sixth-grade classes participated, with the four classes randomly divided into four experimental groups. Thematic analysis, social network analysis, and statistical analysis methods were used to analyze the distribution and transition of roles, the interaction between roles, and the self-efficacy and collective efficacy of the roles. The results illustrated that the role distribution was affected by DSR and ES, and frequent transitions of operational roles in groups emerged when DSR was exchanged. Moreover, the role of ES was reported in this study; it promoted the stability of role interaction on the one hand while significantly promoting self-efficacy and collective efficacy on the other. The study also proposed that the discourse statuses of different roles in collaborative learning were significantly different, and roles with a weaker discourse status had lower self-efficacy.

**Keywords:** Collaborative inquiry learning, Technology affordance, Role interaction, Self-efficacy, Social network analysis

## 1. Introduction

The term “technology affordances” refers to the interactive relationship between the actor and technology (Jeong & Hmelo-Silver, 2016). The affordance of learning technology has been widely discussed in the field of computer-supported collaborative learning (CSCL). When provided with different types of technological support, the learning process varies due to students’ perceived affordance in terms of information acquisition, resource sharing, and process management (Jeong & Hmelo-Silver, 2016). Virtual manipulatives (VM) are computer-based simulations of physical manipulatives (PM) that can be accessed via the Internet or computer software (Bouck & Flanagan, 2009). In science courses, VM running on mobile devices make science inquiry learning flexible and convenient (Jou et al., 2016). Additionally, researchers recognized the role of the mobile device-student ratio on the learning process. Students have better learning experiences and performance with a 1:1 device-student ratio (DSR) due to seamless resource acquisition anytime and anywhere (e.g., Looi et al., 2011; Wong & Looi, 2011). However, some argue that different DSR provides different interaction and collaboration dynamics, for example, a group sharing one device (1:m) may facilitate a full discussion (Lin, et al., 2012). How the DSR influences the interaction patterns of groups remains rare in face-to-face science classrooms. To reveal that the group interaction varies under the impact of the DSR, we considered two conditions: 1:1 and 1:m.

In CSCL, scripts have been widely used to facilitate effective interactions. As socio-cognitive scaffolds for learners (Vogel et al., 2016), external scripts (ES) could structure sequences of activities and role distributions among group members (King, 2007). However, the adverse effects of scripting have been reported in some studies (e.g., Strijbos & Weinberger, 2010). For example, over-scripting may be thought to impede transfer or the development of self-regulatory abilities (Goodyear et al., 2014). Additionally, some studies have indicated ES could moderate the effect of DSR on the learning performance of collaborative inquiry learning (Wang & Le, 2021). The actual interactive process in collaborative learning activities with ES is not clear (Vogel et al., 2016). Therefore, in addition to the DSR, this study considers the effects of ES (with or without) on group interaction patterns in collaborative inquiry learning.

Social interactions in collaborative learning have been a hot topic in recent years. Previous studies focus more on learning outcomes when using VM in collaborative inquiry activities (e.g., Zacharia & Olympiou, 2011). Less attention has been given to how community members communicate with each other under various technical environments. Additionally, roles (e.g., leader, recorder) played by group members could reflect the interaction patterns (e.g., role distribution, role interaction) during group work (Simpson et al., 2017; Kirschner et al., 2018). Moreover, self-efficacy and collective efficacy are important motivational factors that influence group interaction behavior (Wang & Lin, 2007), and they are also affected by the external environment provided. Thus, the purpose of this study is to reveal the effects of DSR and ES on role interactions, self-efficacy, and collective efficacy, as well as the correlation between them.

## 2. Literature review

### 2.1. Technology affordance for collaborative inquiry learning

Gibson (1977) originally defined affordances, referring to possibilities of action provided to an individual by the environment. In CSCL, affordances vary depending on the cultural-symbolic and material properties of the technology (Vyas et al., 2006), as well as how the affordances relate to learners' relevant experience (Jeong & Hmelo-Silver, 2016). Students thus develop perceived affordances for goal-oriented actions when given constraints in a dynamic learning environment (Abrahamson & Sánchez-García, 2016). However, affordances of learning technology need to be examined and understood in terms of what they enable learners to do for greater learning outcomes (Jeong & Hmelo-Silver, 2016).

Collaborative inquiry learning (CIL) originates from the actual activities of scientific inquiry in which students in groups engage in self-regulated learning activities supported by the teacher, and its key features include orientation and questioning, hypothesis generation, planning, investigation, analysis, and interpretation of data, model exploration and creation, conclusion and evaluation, communication, and prediction (Bell et al., 2010). In science classrooms, VM used on tablet PCs is a popular inquiry tool for CIL (Fokides & Mastrokoukou, 2018). Researchers have revealed that VM carries unique affordances compared to PM, including safe and cost-efficient (Hsu & Thomas, 2002), visualization and repeatability (Olympiou & Zacharia, 2012), and flexibility and convenience, especially with the widespread application of mobile technology (e.g., tablet PCs, interactive tabletops) (Jou et al., 2016).

Furthermore, the DSR is an important factor in designing the learning technology environment, especially if the screens are small. For example, Hassler et al. (2016) developed the view that tablets may be best suited for individual rather than collaborative use because of customizability, and some students may be reluctant to share tablets. Researchers have shown that 1:1 DSR could enhance students' learning experience (e.g., Looi et al., 2011; Wong et al., 2010). Lin et al. (2012) summarized the special affordances of the 1:1 DSR as follows: perpetual and ubiquitous learning, authentic and contextualized learning, seamless learning, and rapid knowledge co-construction. Nevertheless, Dillenbourg and Evans (2011) revealed that, while desktops (1:1) are personal, tabletops (1:m) could afford collaboration and facilitate the emergence of different viewpoints in student groups.

Some studies have contrasted students' performances in collaborative learning between the 1:1 and 1:m DSR. For example, Lin et al. (2012) performed quasi-experimental research investigating the effects of two settings on CCM (collaborative concept mapping) in two 6th-grade classes. The findings indicated that the 1:m groups generated concept maps superior to the 1:1 groups due to well-discussed notes, while the 1:1 groups demonstrated better quality interactions. However, the reason why quality interactions did not lead to good production remains unclear. The resource allocation and interaction process may be the factors that influence learning performances in terms of the DSR. However, there are few studies on that topic, and more details need to be revealed.

### 2.2. External scripts in collaborative learning

Students rarely spontaneously generate effective interaction in collaborative learning without some form of guidance (Dillenbourg & Hong, 2008; King, 2007; Kollar et al., 2006). In CSCL, scripts could facilitate the process of collaboration by structuring interactive processes, sequencing the activities, and guiding the discussion (Kollar et al., 2006; Vogel et al., 2016). The learning activities induced by scripts (e.g., roles of participants, the actions engaged in) could prompt specific cognitive, socio-cognitive, and metacognitive processes and closely relate to the intended learning (King, 2007).

There are two kinds of collaboration scripts: internal scripts and external scripts. External scripts (ES) are usually provided by teachers or learning facilitators to prompt group interaction (King, 2007) not otherwise represented in learners' cognitive systems but rather in their external surroundings, typically at the beginning of a collaborative learning situation (Kollar et al., 2006). In contrast, internal scripts often refer to an internalized version of an ES. It may also refer to prior socially/culturally derived rules for cooperating (King, 2007). Thus, internal scripts exhibited interindividual differences with respect to their degree of structuredness, which was related to individuals' concrete experiences with situations (Kollar et al., 2006). Dillenbourg identified five types of ES according to the level of coercion. Specifically, induced scripts convey the designer's expectations implicitly; instructed scripts are oral or written instructions of the teacher's expectations by which students can construct an internal script that corresponds to the ES; trained scripts train students to collaborate in a specific way and may have control over the student's internal script; prompted scripts provide cues that direct students to specific roles; follow-me scripts strictly control how students interact with an environment (Dillenbourg & Jermann, 2007). Instructed and prompted scripts are often used in CIL of science courses, not only allow students to develop their internal scripts, but also facilitate group interaction by special roles.

Previous studies have found that CSCL with ES had a large positive effect on the collaboration skills and learning outcomes of students in domain-specific knowledge areas (Radkowitsch et al., 2020; Vogel et al., 2016). However, ES may influence naturally emerging collaboration and are not conducive to self-regulatory abilities (Goodyear et al., 2014). Therefore, this study will also explore the effect of ES on CIL.

### 2.3. The roles, self-efficacy, and collective efficacy

The assignment of group roles is an important indicator of the performance of group coordination (Strijbos et al., 2007), can promote the formation of positive interdependence, and contributes to the success of collaboration (Antle, 2014). There are two perspectives about roles in CSCL, namely, emerging roles and scripted roles. Emerging roles are spontaneously developed by participants, emphasize the learner's structure, and self-regulate their CSCL processes (Strijbos & Weinberger, 2010). The development of emerging roles is dynamic over longer periods according to learners' knowledge acquisition and collaborative learning experiences (Strijbos & Weinberger, 2010). However, spontaneous role participation is often unequal participation (Simpson et al., 2017; Lloyd & Cohen, 1999). For example, Simpson et al. (2017) detected uneven participation patterns, unequal status orderings, and an imbalance of power in group interactions. In contrast, script roles are assigned to learners by educational designers to promote equal participation of group members and structured collaboration. Both emerging roles and script roles could influence the interaction patterns of collaborative groups; thus, we will discuss their interactions.

Specifically, what roles will appear in the process of collaboration? In face-to-face CIL, each role has implicit responsibility for information processing, cognitive participation, and so on, but to complete a task together, each role has explicit behavior responsibility. Accordingly, role categorization of function may reflect group interaction patterns. Johnson and Johnson (1987) classified the functions of roles in group collaboration into four categories: formative, functional, summative, and promotive. An example of a formative role could be order supervisor, while functional roles include recorder, motivator, clarifier, interpreter, and consensus seeker. Summative roles contain summarizer and creator, while the duties of promotive roles include reason requesting and principle giving (Johnson & Johnson, 1987). Furthermore, Wang (2021) identified five functional role categories in CIL in science courses, including coordinator, integrator, inquirer, facilitator, and marginal. The categories will be used in this study to identify roles that emerge in CIL.

Self-efficacy (SE) and collective efficacy (CE) are the motivating factors for collaborative learning. SE (students' perceptions of their capability to achieve the desired outcome) is specifically related to the learning experience and the external environment (Bandura, 1997) and may also affect learning cognitive processes (Girasoli & Hannafin, 2008) and academic achievement (e.g., Tsai et al., 2011). In CSCL, researchers have suggested that collaborative learning behavior may be influenced by the SE of group members (Wang & Lin, 2007). CE refers to the group's shared beliefs in its conjoint capabilities to execute the courses of action required to achieve designated goals (Bandura, 1997). According to Wang et al. (2014) and Wang and Lin (2007), CE has a positive impact on group performance and could be affected by group interaction behaviors due to students with higher collective efficacy using more high-level cognitive skills in group discussions (Wang et al., 2014). However, few researchers have explored the influence of different technology affordances on SE and CE in collaborative learning. Therefore, in addition to examining the involvement and interaction of roles, this study investigates the SE and CE of roles in different technology affordances.

### 2.4. Purposes of this study

We conducted two-round CIL activities in a primary school to depict how roles variously respond to the DSR exchange under the impact of ES. There are two independent variables: device-student ratio (DSR) and external script (ES). The symbol 1:1 DSR represents each student has a tablet, while the 1:m DSR demonstrates only one tablet for each collaborative group. The mark (with or without) under ES refers to whether external support was provided to facilitate collaboration through structuring the interactive processes. In terms of dependent variables, we discussed four aspects: role distribution, role interaction, self-efficacy (SE), and collective efficacy (CE). The Roles refer to each group member's responsibilities, which include coordinator, integrator, inquirer, facilitator, and marginal. The proportion of five role categories that emerge during inquiry processes is referred to as role distribution. Role interaction refers to the closeness of interaction among group members and the interaction patterns of groups. SE and CE reflect learners' beliefs about individual and group capability in CIL. In summary, four main research questions are addressed as follows:

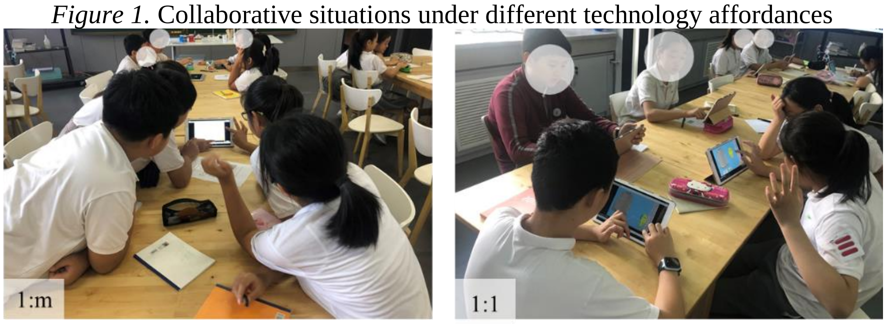
- How did the DSR exchange impact role distributions with and without ES?
- How did the DSR exchange impact role interactions with and without ES?
- How did the DSR exchange impact SE and CE with and without ES?
- What is the relationship between roles, SE, and CE?

## 3. Experimental design

### 3.1. Participants

The study involved 128 children, aged 10-12, in sixth grade (69 girls, 59 boys). They were from four classes of a public primary school located in Beijing, China, and taught by the same science teacher. An informed consent form that included detailed information about that experiment was signed by all participants, parents, and science teachers. We termed these four classes Class A (15 boys, 16 girls), Class B (16 boys, 18 girls), Class C (16 boys, 16 girls), and Class D (12 boys, 19 girls). Figure 1 depicts the collaborative situations in the two DSR conditions. Students in each class were randomly assigned to 6 learning groups, with 5-6 students in each group. These groups were long-term cooperative learning groups and had loyal interpersonal relations and adequate prior team experience (Johnson & Johnson, 1999). Additionally, there was no significant difference in the science exam in the last academic year among these four classes ($p$ = .167 > .05). It should be noted that 11 students did not accomplish all experimental procedures due to various factors, such as time conflicts, students' physical conditions, and learning situations. Thus, the error caused by the 11 dropout students could be viewed as a limitation in this study.

*Figure 1.* Collaborative situations under different technology affordances

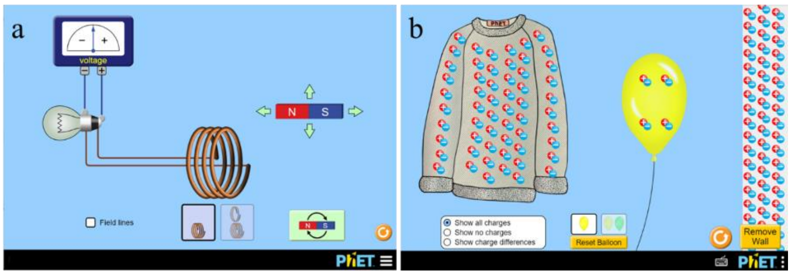



### 3.2. Inquiry technologies

#### *3.2.1. Virtual manipulatives*

The scientific inquiry theme in the first round is electromagnetic induction (Mag.), and the theme after affordance exchange is triboelectrification (Fri.). They were chosen from the contents of the fifth- and sixth-grade science curriculum according to the syllabus of the selected school. Accordingly, VM was selected from the PhET learning platform (phet.colorado.edu), a free online simulation program. These two topics are related and have the same level of difficulty, and the operation of VM is essentially the same. These simulations run independently and separately on tablets running on Android, with a screen size of 8 inches and a screen ratio of 16:10 (see Figure 2). Before conducting experiments, all participating students had prior experience using these tablets for learning. In 1:1 DSR, each student could operate and observe using his or her own tablet anytime and anywhere. However, group members in 1:m DSR share one tablet for operation and observation, necessitating negotiation over the use of restricted resources.

*Figure 2.* Interactive interface of VM: a. Mag; b. Fri.




### *3.2.2. External scripts*

This study designed two types of ES. Instructed scripts were guidelines for the CIL provided by the science teacher through PowerPoint to students (see Figure 3), while prompt scripts were cues that inspired students to play a particular role (see Figure 4). During the collaboration, students could play most of the roles on their own according to the prompt. However, for all group members' discussions, the scripted role of "inspector" was delegated to particular students.

*Figure 3.* Instructed script

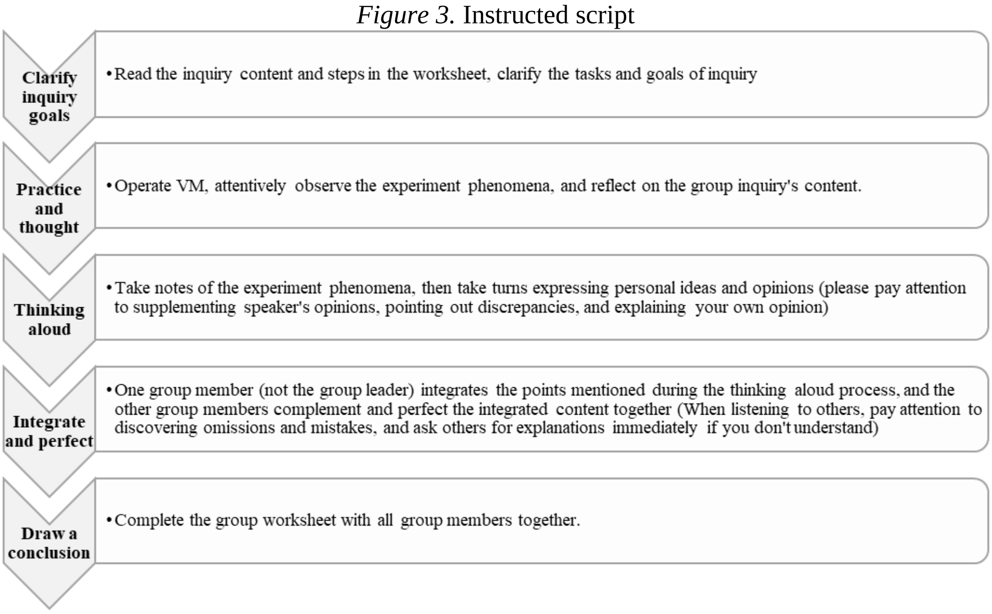



*Figure 4.* Prompt script

**The function of Inspector**

- Keep the discussion from getting sidetracked
- Remind group members to follow the experiment requirements
- Manage the inquiry process and allocate time reasonably
- Facilitate all group members to participate in the collaborative inquiry

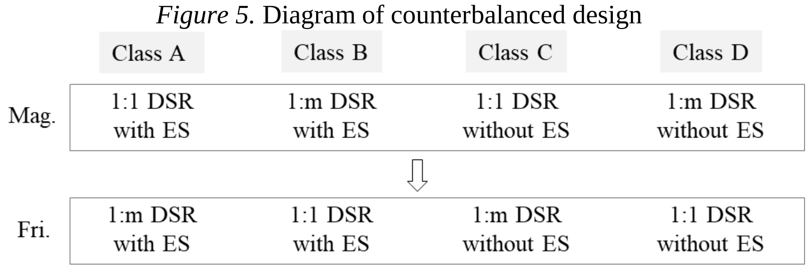
### *3.2.3. Group worksheet*

Students were also driven by group worksheets jointly developed by the science teacher and the researchers in conformity with the science curriculum standards. In each group worksheet, there were two inquiry tasks. They were designed to examine the students' concept interpretation and problem-solving competence, respectively. The worksheet's total score was 100 points, with 50 points each for the two tasks. We also obtained the group members' seat details from the worksheets.

### 3.3. Procedure

In keeping with the school's science curriculum, this research was performed in two-round in June and September 2019. In the first round, the inquiry situations of the four classes were as follows: A: 1:1 DSR and with ES; B: 1:m DSR and with ES; C: 1:1 DSR and without ES; and D: 1:m DSR and without ES (see Figure 5). In the second round, the status of DSR for each class was exchanged, such as class A/C from 1:1 to 1:m and class B/D from 1:m to 1:1; simultaneously, the availability of ES remained the same.

*Figure 5.* Diagram of counterbalanced design




Inquiry learning activities have three steps. The teacher introduces the inquiry task in the first step (10min). Specifically, the teacher presents and explains the instructed script and distributes the prompt script to groups with ES. Step two is for groups to do independent inquiry and finish the worksheet without the teacher's intervention (25min). The final step is to instruct all students to complete a reflection questionnaire (10min).

### 3.4. Instruments

A reflection questionnaire, created by two primary science teachers and one primary Chinese teacher, was used to collect the relevant information of students during the inquiry processes. This questionnaire consists of two parts: (1) three open-ended questions about roles and (2) two efficacy items that used a seven-point Likert scale. The three open-ended questions are as follows: (a) What tasks and roles did you play in the group inquiry? (b) How did your group use the tablet(s) to collaborate? (c) Which group members did you communicate more with? Three questions were used to investigate the emerged roles, the way students used learning resources, and the interaction among group participants during the group inquiry process.

The items of SE and CE were inspired by the PASS scale established by Pass in 1992. This scale is probably the most commonly used subjective appraisal scale. It contains only a nine-point scale item, namely, "How much mental effort did you put into the learning process?" (Paas, 1992). Thus, this study used two seven-point scale items: (a) "My success in this task in group collaboration was…"; and (b) In this task, my group's performance in the class was…". The options ranged from (1) "very poor" to (7) "very good".

### 3.5. Data analysis

#### *3.5.1. Thematic analysis*

A qualitative thematic approach was applied to analyzing role information reported by students in the reflection questionnaire. The role information was encoded based on the codes proposed by Wang (2021). In this study, first, the work content with similar characteristics was summarized into abstract role labels; second, the role labels were classified into five categories (see Table 1). We tested the consistency of role coding results of the two researchers for the two-round experiments. The inter-rater reliability Kappa was .839 ($p$ < .001, $N$ = 245), which indicates good consistency. The science teacher was invited to examine the divergence between two researchers' coding results and collaborate with the researchers to unify the inconsistency.

*Table 1*. The role labels and categories in this study

| Role category | Role label | Role definition | Examples of students description |
|---|---|---|---|
| Coordinator (R1) | Leader | The group leader is assigned by the teacher and leads the group to complete the task | "lead group members to explore learning tasks" |
| | Inspector | Script role (Figure 4) | "identify the content of exploration and prevent discussion deviation" |
| Integrator (R2) | Recorder | Recording inquiry processes and findings according to the group worksheet | "participate in discussions and record answers" |
| | Integrator | Summarizing ideas and suggestions | "summarize" |
| | Leader & Recorder | Acts as both leader and recorder | "the group leader, and wrote worksheet" |
| | Inspector & Recorder | Acts as both inspector and recorder | "I was an inspector and wrote worksheets meantime" |
| Inquirer (R3) | Investigator | Proposing solutions to problems and drawing conclusions | "explore to find the answer to the question" |
| | Experimenter | Operating the tablet(s) to conduct the experiment | "primary operator, operating tablet computers" |
| Facilitator (R4) | Proposer | Offering suggestions | "I'm an idea person to the group" |
| | Facilitator | Assisting group members in completing the inquiry tasks | "assist others" |
| Marginal (R5) | Observer | Just observing the whole process of inquiry | "listen to the team members" |
| | Spectator | Regarding oneself as the spectator/outsider of the group | "audience, watching other people" "play soy sauce", "silent bear" |
| | （null） | Students did not report the played role | |

### *3.5.2. Social network analysis*

In this study, the social network analysis method was applied to analyze the interaction of group members' roles. The data source is the actual seating information filled in by the students in group worksheets, that is, the proximity relationship of group members, as well as the member communication reported in the reflection questionnaire. We use two concepts (density and component) to extract the social network characteristics of groups. First, network density represents the closeness of interactions among group members. The value range of density is [0, 1], and the more connections between nodes, the higher the network density is. The network density of the social network graph with directional arrows can be expressed by the following formula, where the symbol $n$ represents the number of nodes and the symbol $d_i$ represents the degree of node $i$.

$$\sum d_i / n(n-1)$$

Second, the "action-oriented component" was used to analyze the focus of the group work in the inquiry activity. A component refers to the subgraph of a social network graph with all nodes connected (Marin & Wellman, 2011). This study selected the in-degree of nodes to extract the components of the directed graph. To find the "action-oriented component," initially, the node with the highest in-centrality in a group was marked. Then, starting from this node, we found the component with 3 nodes and selected the component with the highest in-centrality degree. If multiple components with the highest in-centrality degree were found, the component with the most two-way connections was selected. If a group did not contain such components, this group could be considered a non-oriented group. Based on identified network components, this study divided the action orientation of participating groups into three types: task-oriented, inquiry-oriented, and non-oriented. For visualization, they were assigned values of 1, -1, and 0.

- Task-oriented group: the action-oriented component contained R2, and the in-degree of R2 was not 0. These groups focused on completing group worksheets.
- Inquiry-oriented group: the action-oriented component contained R3 but did not contain R2, or the in-degree of R2 was 0. These groups focused on operating the VM and conducting an inquiry.

- Non-oriented group: the action-oriented component contains R2 roles with a 0 in-degree of recorders but no R3 roles; or does not contain R2 and R3 roles; or there was no action-oriented component.

#### *3.5.3. Statistical analysis*

As the SE and CE scores of students do not meet normal distribution, respectively nonparametric tests such as the Jonckheere-Terpstra test, the Mann-Whitney U test, and the Wilcoxon signed-rank test were used for revealing differences. Additionally, the group learning performance (the score of the group worksheet) was analyzed using two-way ANOVA. The statistical analysis was performed using SPSS24.0 with $p < .05$ defined as statistically significant.

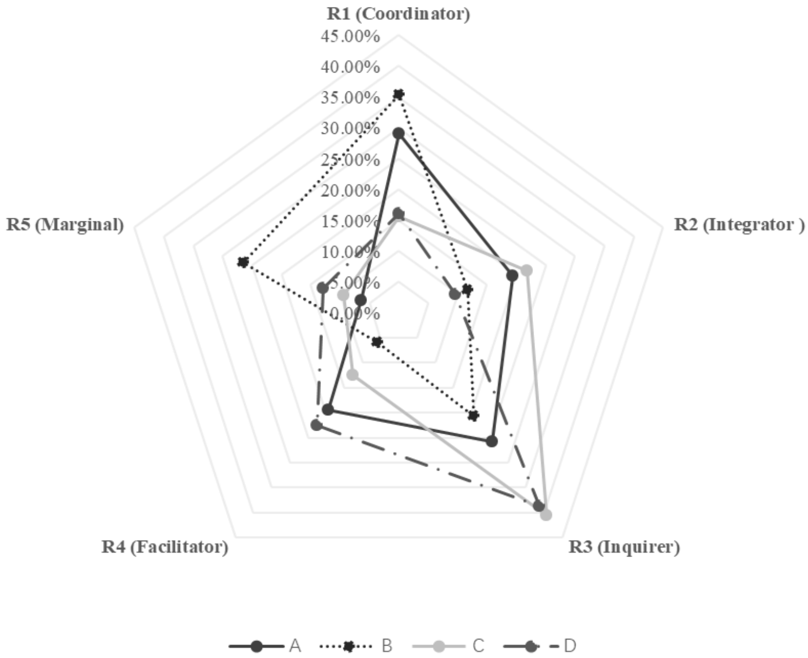
## 4. Results

### 4.1. Role distribution and transition

#### *4.1.1. Role distribution*

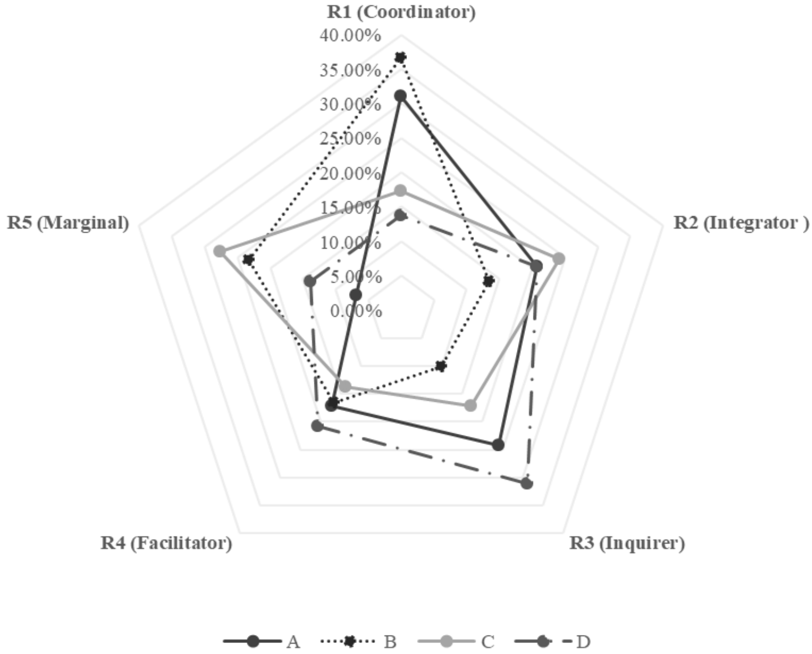
According to the results of thematic analysis, the proportion of the five role categories of participating classes was calculated in this study. A radar map was applied to illustrate the distribution proportion (Figure 6, Figure 7). In Mag, different classes exhibit varying characteristics of role distribution. First, classes B and A (with ES) had more coordinators and fewer inquirers than Classes C and D (without ES). Second, classes A and C had more integrators and fewer marginals than classes B and D.

*Figure 6.* The radar map of role distribution of Mag




From Figure 7, the role distribution had some obvious changes after DSR was exchanged. With ES, the role distribution of Class A was mainly similar to before; however, facilitators increased, and inquirers decreased in Class B. Without ES, the inquirers decreased in Class C, while the marginals increased. Additionally, there were more integrators than before in Class D.

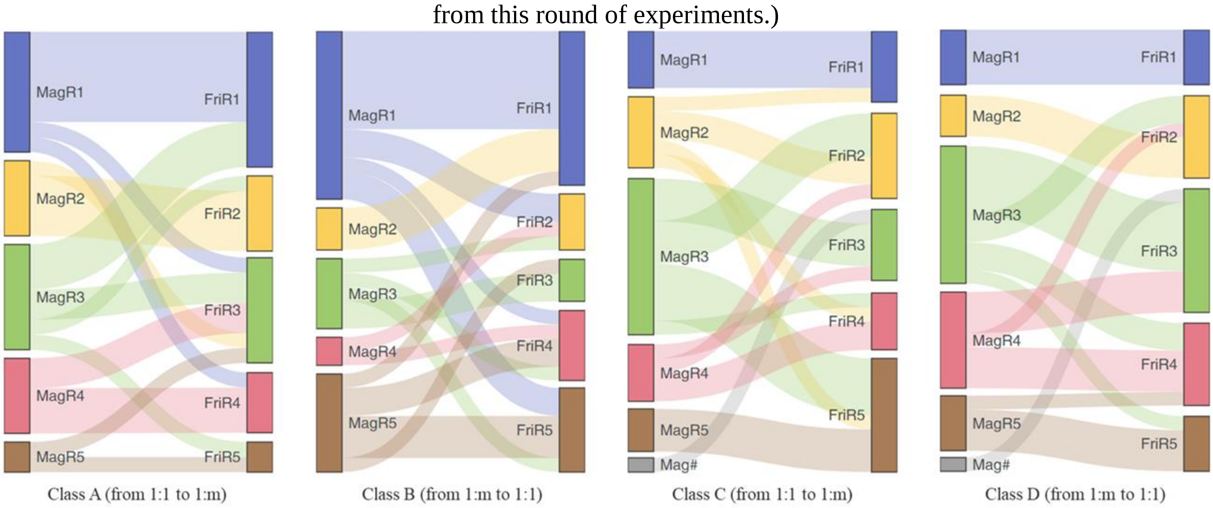
*Figure 7.* The radar map of role distribution of Fri




### *4.1.2. Role transition*

In inquiry experiments, only the group leader was fixed, and other roles flowed and changed according to the self-regulation of the group. A Sankey diagram was applied to visualize the role transitions of the four participating classes (see Figure 8).

*Figure 8.* The Sankey diagram of role transition (*Note.* The symbol "#" indicates the students who were absent from this round of experiments.)




As shown in Table 2, when DSR exchanged from 1:1 to 1:m, both Class A and C had a comparatively large number of substitutions of inquirers with other categories. The majority of category transitions in Class A (with ES) were R3 to R1 and R4 to R3, i.e., the work shifted from inquirer to inspector or from facilitator to inquirer. Additionally, most category transitions in Class C (without ES) were R3 to R5 or R2. Most of the inquirers shifted to marginals or integrators, and the role distribution structure changed significantly.

As DSR exchanged from 1:m to 1:1, role transition in class B (with ES) was more frequent, primarily as follows: R1 to R2 or R5; R2 to R1; and R5 to R4. Specifically, some coordinators (group leaders or inspectors) shifted their work focus from coordination to integration, with two inspectors even became spectators. All integrators transformed into coordinators (three recorders were reassigned to inspectors), and two spectators also transformed into facilitators. In Class D (without ES), the transition of roles was relatively sparse compared to other classes, namely, R4 to R3, and R3 to R2 or R4. Approximately 50% of facilitators shifted to inquirers, while a small portion of inquirers shifted to integrators or facilitators.

In conclusion, the probabilities of role transition were highest for the inquirer (63.64%), and the inquirer may shift to various categories. Second, most transitions were facilitators (50%) and integrators (43.75%). However, the coordinator (the leader is fixed) and marginal categories were relatively stable.

*Table 2.* Role transition probabilities

| | Fri | R1 | R2 | R3 | R4 | R5 | Total |
|---|---|---|---|---|---|---|---|
| Mag | R1 | **21 (75%)** | 2 (7.14%) | 1 (3.57%) | 2 (7.14%) | 2 (7.14%) | 28 (100%) |
| | R2 | 4 (25%) | **9 (56.25%)** | 1 (6.25%) | 1 (6.25%) | 1 (6.25%) | 16 (100%) |
| | R3 | 3 (9.09%) | 7 (21.21%) | **12 (36.36%)** | 4 (12.12%) | 7 (21.21%) | 33 (100%) |
| | R4 | | 3 (16.67%) | 6 (33.33%) | **9 (50%)** | | 18 (100%) |
| | R5 | 1 (6.25%) | | 2 (12.5%) | 3 (18.75%) | **10 (62.5%)** | 16 (100%) |
| | # | | | 2 (100%) | | | 2 (100%) |

*Note.* The symbol "#" indicates the students who were absent from this round.

## 4.2. Role interaction

### *4.2.1. The density and components of group networks*

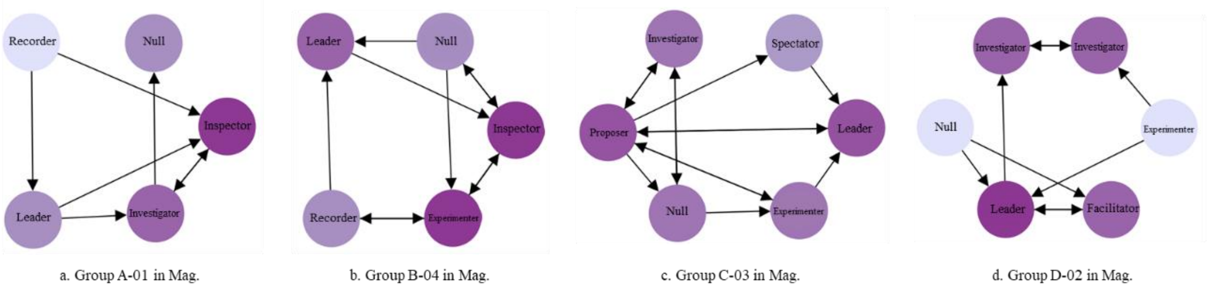
We used Gephi software to map the group's social network (see Figure 9). In the group social network graph, the node contains a role label, and the directed edges represent interactional relations between members. For instance, A→B indicated that A replied in the reflection questionnaire that A and B had more communications. Therefore, the in-degree of a node represented the importance of the corresponding student in the group inquiry. The network density and the action orientation of the participating groups are illustrated in Table 3.

*Table 3*. The network density and action orientation of groups

| Inquiry themes | Mag | | Fri | |
|---|---|---|---|---|
| Class-group | Network density | Action orientation | Network density | Action orientation |
| A-01 | 0.35 | -1 | 0.35 | -1 |
| A-02 | 0.40 | 1 | 0.42 | 1 |
| A-03 | 0.30 | 1 | 0.50 | 1 |
| A-04 | 0.45 | 1 | 0.50 | 1 |
| A-05 | 0.45 | 1 | 0.50 | 1 |
| A-06 | 0.25 | -1 | 0.50 | -1 |
| B-01 | 0.17 | 0 | 0.35 | 1 |
| B-02 | 0.23 | -1 | 0.33 | -1 |
| B-03 | 0.30 | 0 | 0.35 | -1 |
| B-04 | 0.50 | 1 | 0.58 | 1 |
| B-05 | 0.20 | 0 | 0.30 | 0 |
| B-06 | 0.60 | -1 | 0.45 | 0 |
| C-01 | 0.30 | -1 | 0.40 | 1 |
| C-02 | 0.75 | 1 | - | 0 |
| C-03 | 0.43 | -1 | 0.43 | 0 |
| C-04 | 0.33 | 1 | 0.33 | 1 |
| C-05 | 0.30 | 1 | 0.50 | 1 |
| C-06 | 0.45 | -1 | 0.35 | 1 |
| D-01 | 0.60 | -1 | 0.30 | 1 |
| D-02 | 0.30 | 0 | 0.25 | 0 |
| D-03 | 0.60 | 1 | 0.58 | -1 |
| D-04 | 0.50 | 1 | 0.37 | 1 |
| D-05 | 0.45 | 0 | 0.45 | -1 |
| D-06 | 0.40 | -1 | 0.25 | 1 |

*Note.* The symbol "-" in Network density represents there are only two students in group C-02 in Fri.

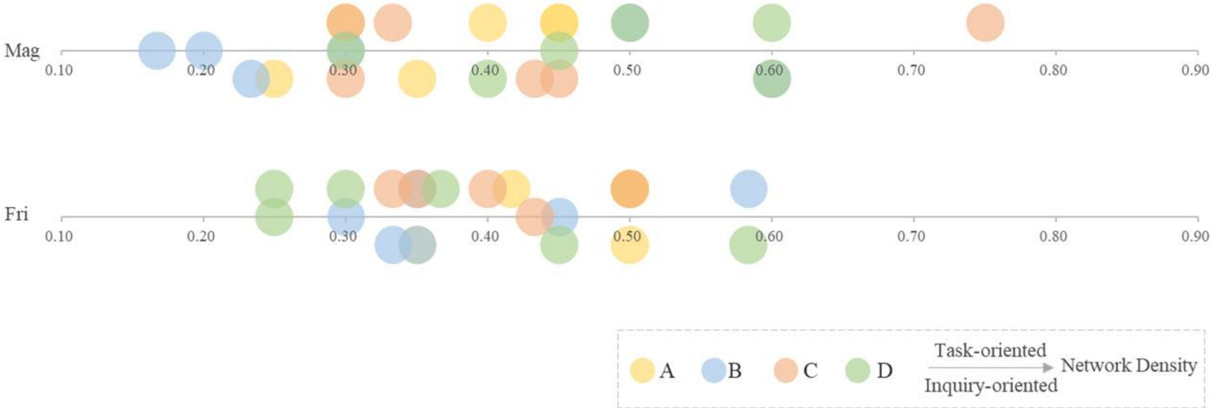
*Figure 9.* Example graphs representing group social network




### *4.2.2. The change of role interaction*

Figure 10 visualizes the closeness and pattern of role interaction of groups according to Table 3. In Figure 10, dots represent participating groups, and the horizontal axis represents the network density of the group. The dots located above the axis (value was 1) were task-oriented groups; the dots located below the axis (value was -1) were inquiry-oriented groups. In addition, the dots located on the axis (value was 0) were groups without obvious action orientations.

*Figure 10.* The closeness and pattern of role interaction (*Note.* The transparency of dots is 80%, the color where the dot's color does not match the figure legend indicates that there are more than one dots located in the same position, that is, the network density and the action orientation of the several groups are the same.)




As for network density, in Mag, the ES actually reduced the interaction density of the group, especially in 1:m DSR. The descending order of interaction density was Class D, Class C, Class A, and Class B. When the DSR was exchanged in Fri, the network density of class B was significantly increased. However, the network density of Class D was reduced. In Class A, the network density was also improved, while Class C had no significant changes. This might show that the interaction degree of the group would be improved when the DSR was exchanged under ES. In the matter of action orientation, there was no obvious trend in Mag. However, in Fri, Class C and D had more changes in action orientation than Class A and B. The groups with ES are likely to have a more stable action orientation when the DSR was exchanged.

## 4.3. Self-efficacy and Collective efficacy

### *4.3.1. Effects of external scripts*

Two separate Jonckheere-Terpstra tests were used to analyze the differences of SE and CE among the four classes (see Table 4). Consequently, there were significant differences of SE and CE in Fri ($p$ = .021, $p$ = .004). Further the Mann-Whitney U test was applied to compare two classes (A and C; B and D; A and B; C and D) in Fri. The results showed that there were significant differences in CE between Class A and C ($U$ = 300.5, $z$ = -2.02, $p$ = .043), and in CE and SE between Class B and D ($U$ = 310, $z$ = -1.991, $p$ = .047; $U$ = 297.5, $z$ = -2.225, $p$ = .026). Additionally, the respective mean values of SE and CE with ES (Class A and B) were higher than those without ES (Class C and D) in the two-round of experiments. This might imply that ES could facilitate students' SE and CE in the long term.

*Table 4.* Jonckheere-Terpstra test of SE and CE of four classes

| | | *SE* | | *CE* | | *N* |
|---|---|---|---|---|---|---|
| | | Mean Rank | *J-T* | Mean Rank | *J-T* | |
| Mag. | A | 69.63 | -.806 | 71.76 | -1.380 | 31 |
| | B | 66.71 | | 65.65 | | 34 |
| | C | 55.58 | | 59.95 | | 32 |
| | D | 66.16 | | 60.68 | | 31 |
| Fri. | A | 64.93 | -2.301* | 69.40 | -2.862** | 29 |
| | B | 67.88 | | 65.12 | | 30 |
| | C | 52.95 | | 52.57 | | 29 |
| | D | 49.93 | | 48.71 | | 29 |

*Note.* $^{*}p < .05$; $^{**}p < .01$.

#### *4.3.2. Changes in SE and CE*

To explore the changes in SE and CE before and after the exchange of the DSR, the Wilcoxon signed-rank test was conducted on the two-round of data in the same class. The results showed that there was no significant difference in either SE or CE. However, in Fri, the respective mean values of SE and CE decreased in Class A, C, and D, while the respective mean values of SE and CE increased in Class B.

### 4.4. Relationships between roles, SE, and CE

The results of the Jonckheere-Terpstra test (see Table 5) revealed a significant difference in SE scores among the five role categories ($p$ = .035). The SE scores of two role categories of all combinations were further compared using the Mann–Whitney U test. There was significant difference in SE between R1 and R5 ($U$ = 876.5, $z$ = -2.276, $p$ = .023). Additionally, the respective mean values of SE and CE of R5 are lower than those of other role categories.

*Table 5.* Jonckheere-Terpstra test of SE and CE of five role categories

| | *SE* | | *CE* | | *N* |
|---|---|---|---|---|---|
| | Mean rank | *J-T* | Mean rank | *J-T* | |
| R1 | 138.31 | -2.112* | 133.27 | -1.335 | 60 |
| R2 | 119.79 | | 122.24 | | 43 |
| R3 | 119.13 | | 114.92 | | 64 |
| R4 | 129.09 | | 138.79 | | 39 |
| R5 | 103.26 | | 105.50 | | 39 |

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

In addition, this study analyzed the scores of group worksheets under four conditions. The Kolmogorov-Smirnov test demonstrated that the data are normally distributed ($z$ = .89, $p$ = .407 > .05). The data are also homoscedastic ($F$ = .536, $p$ = .66 > .05) according to Levene's test. It was found that the DSR had a significant impact on the learning performance ($F$ = 16.596, $p$ < .001) through two-way ANOVA (see Table 6). The learning performance of 1:m groups was significantly better than that of 1:1 groups. However, the ES had no significant impact on the group learning performance.

*Table 6.* Between-effects of factors on learning performance ($N$ = 48)

| | *F* | Partial $\eta^2$ |
|---|---|---|
| DSR | 16.596*** | .274 |
| ES | .049 | .001 |
| DSR*ES | .049 | .001 |

*Note.* $^{***}p < .001$.

## 5. Discussion

### 5.1. Role distribution was affected by DSR and ES

In this study, the concept of role is from the perspective of the task, which is more in line with the collaboration of primary school students (Strijbos & De Laat, 2010). The role reflects the individual's self-awareness about their position in the group. Therefore, role distribution represents how the group works together (Kirschner et al., 2018). By analyzing the difference in role distribution under different conditions, we found that the DSR and the availability of ES affected role distribution interactively. Specifically, when guided by ES, there were more scripted roles, such as leaders and inspectors. According to Strijbos and Weinberger (2010), coordinators play a process-oriented role and facilitate indirect learning by dividing tasks and coordination. Without ES, the collaborative groups were not restricted by external rules but formed internal behavioral patterns by self-regulation (Wang et al., 2017), and more inquirers emerged. However, such differences did not affect the group learning performance.

Under the 1:1 DSR, the operation interface and observation of phenomena were not usually shared in groups, and the knowledge generated during the inquiry process was stored in group members in a distributed manner. Under this constraint, more integrators would be generated. The process of collaboration was described as "inquire by themselves, then discuss" or "everyone did experiment and then drew conclusions" (descriptions in the reflection questionnaire). In contrast, under 1:m DSR, the operation interface was usually shared in real-time. Inquiry activities include collective behavior, as they described it, "we use the tablet together, and discuss the problem together," and "a group with a tablet is easier to discuss." Thus, there were fewer integrators. This can also explain why the learning performance of the group in the 1:m DSR is better than 1:1 DSR. This is consistent with the results of Lin et al. (2012). However, limited by the opportunity to operate VM, it was easy to produce marginal results. According to Simpson et al. (2017), roles with higher status had more control over sharing technological devices, and vice versa. This explained why there were obviously more marginal effects at the 1:m DSR compared with 1:1 DSR.

### 5.2. Frequent transitions of operational roles in groups emerged when DSR exchanged

How did the DSR exchange impact role distribution? We found that the group carried out internal coordination of roles to adapt to the new resource usage pattern. The division of tasks has changed. The transition of inquirers (R3) was the most obvious, especially from 1:1 to 1:m, which indicated that the ownership of tech tools (Antle, 2014) affected their role perception. For example, a student in Class B wrote that he thought he was "a bystander" because "someone has been operating the tablet" in Mag. However, in Fri, "everyone got a tablet," and he thought of themselves as "explorers." In addition, the role of ES was not clear on role transitions, even though ES may promote the formation of a reasonable role distribution, especially from 1:1 to 1:m (comparison between Class A and Class C). Only in the two-round of experiments could we not see the regular transitions of roles. Perhaps in the longer term, there would be some stable changes according to the development of role knowledge and collaboration skills (Strijbos & Weinberger, 2010).

### 5.3. ES promoted the stability of role interaction and affected SE and CE

In terms of role interaction, ES played a significant role. On the one hand, it may weaken interaction density in this study even though it showed no effect on group learning performance. This is contrary to Dillenbourg and Jermann (2007); the richness and intensity of interactions between group members determined the effects of collaborative learning. As Vogel and his colleagues (2016) pointed out, the effects of collaboration may be more dependent on the amount of practice of the corresponding activities than on the transitivity of the interaction. On the other hand, when the DSR was exchanged, ES promoted the stability of role interaction, such as more groups having changed action orientation in classes that do not provide ES. When the group has formed a certain interactive mode, the exchange of DSR means a new adaptation. The mean value of students' SE and CE in Class A, C, and D decreased in the second round, indicating that the DSR exchange is a challenge for collaborative learning. In this case, the scaffolding role of the ES could be well-reflected.

At the same time, in Fri, the SE and CE of the scripted classes were significantly higher than that of the unscripted classes. Previous researchers have found that CSCL with ES had a large positive effect on students' collaboration skills and learning outcomes on domain-specific knowledge (Radkowitsch et al., 2020; Vogel et al., 2016). Furthermore, we found that ES could promote learners' SE and CE in the long term. This may be because ES reduced the difficulties of intragroup coordination, such as division of labor and digression.

### 5.4. The roles with weaker discourse status had lower SE

Despite the benefits of collaborative learning, uneven participation of roles has been reported in some studies (e.g., Simpson et al., 2017). This study also found that the discourse statuses of the roles were different. The group social network revealed that the interaction of most groups was led by 2-3 roles, generally, the coordinators, integrators, and inquirers, who formed the center of the groups. However, the in-degree of most of the marginal roles $\leq 1$. We also found that the SE level of the five role categories were significant different; concretely, the SE of R1 is significantly higher than R5. The status of students in groups is influenced by many factors, such as their interest in exploring the topic and their perceived differences in abilities compared to other group members (Simpson et al., 2017). Additionally, Strijbos and De Laat (2010) pointed out that learners' participation in the collaboration process is influenced by their participation stance, which is related to learning motivation and experience. These differences result in some students doing most of the work and some doing less. In this study, marginals might develop low SE due to a poor collaborative experience. In the reflection questionnaire, we can also feel the loneliness of this type of role: "do nothing," "I can only watch," "soy sauce," "useless guys," (students' descriptions of tasks and roles).

## 6. Conclusions

This study explored the influence of DSR and ES on CIL. A counterbalanced design of CIL was conducted in four primary school classes. Thematic analysis, social network analysis, and statistical analysis methods were used to analyze the distribution and transition of roles, the interaction between roles, and the SE and CE of the roles. The implication for practice in this study is to help design a collaborative learning environment in science courses. For example, the exchange of DSR can be used to achieve spontaneous role transition, and scripted roles can be designed to promote effective group interaction, such as inspectors. In addition, we need to recognize the marginal roles in collaborative learning and design scaffolds for them. Referring to limitations, 11 students were absent from the second experiment, which impacted group interaction. Moreover, there are influences that are not excluded, such as subject matter. However, this is difficult to avoid when conducting empirical research in authentic classrooms. How to achieve effective and equal collaboration in the role of group members is a problem worthy of further discussion.

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