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# Exploring the behavioral patterns of Co-regulation in mobile computer-supported collaborative learning

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**Abstract**

This study examined the behavioral patterns of co-regulation in a mobile computer-supported collaborative learning context. Participants in this study included 101 undergraduate students majoring in law or Chinese language and literature. Content analysis and lag sequential analysis were conducted to analyze the behavioral patterns of co-regulation for four weeks. The results indicated that the main co-regulation behaviors included establishing goals, making plans, enacting strategies, monitoring and controlling, reflecting and evaluating, and adapting metacognition. The behavioral sequences from week 1 to week 4 demonstrated different characteristics. In addition, the high-achievement groups and low-achievement groups presented distinct differences in behavioral sequences. The implications for CSCL and limitations are also discussed.

**Keywords:** Co-regulation, Behavioral pattern, Computer-supported collaborative learning, MCSCL

## Introduction

Computer-supported collaborative learning (CSCL) has been widely adopted in schools, universities, and workplaces. Positive outcomes originating from collaborative learning have been reported in numerous studies (Web and Palincsar 1996; Veenman et al. 2005; Tsai 2011; Järvelä and Hadwin 2013). However, dividing students into groups does not necessarily result in productive collaborative learning (Barron 2003). Group members need to know how to regulate their learning processes (Kreijns et al. 2003). In the CSCL context, group members have to co-regulate each other to jointly solve problems. They can ask questions, provide explanations, elaborate on concepts, monitor progress, correct errors, and evaluate outcomes in order to gain a better understanding of the subject matter. Moreover, co-regulatory abilities are considered important for improving the quality of collaborative learning (Ucan and Webb 2015). Recently, mobile computer-supported collaborative learning (MCSCL) attracted much attention since various kinds of APP have been developed to facilitate the implementation of MCSCL (Song 2014). The present study aims to explore the behavioral patterns of co-regulation in the MCSCL context.

## About Co-regulation

Co-regulation can be characterized as an externally initiated regulatory process that promotes traits of self-regulation in individuals and traits of shared cognition and distributed cognition in groups (Zheng et al. 2014). Co-regulation is a dynamic process that is mediated by social interactions. Typically, co-regulation describes the social interactions that occur between two or more group members in a CSCL context (McCaslin and Hickey 2001). Moreover, co-regulation builds on Vygotsky's (1978) theory that higher psychological processes in individuals originate from social interaction. Learning occurs inter-subjectively, mediated by social interaction, before it occurs intra-subjectively (Vygotsky 1978).

Co-regulation is an expansion of self-regulation, as it also encompasses cognitive and social aspects (Chan 2012). Co-regulation implies that individuals collaborate as multiple self-regulating agents socially regulating each other's learning processes (Volet et al. 2009). The main difference between self-regulation and co-regulation is who regulates during the learning process. Self-regulation emphasizes that each individual independently regulates his or her own learning processes, whereas in co-regulation, individuals regulate each other's learning. If a student is self-regulated, it does not mean that he or she can co-regulate in a group (Chan 2001). Co-regulation requires the ability to regulate one another's motivation, emotion, cognition, and metacognition.

## Co-regulation in CSCL

CSCL is an approach to learning in which group members jointly solve problems and co-construct knowledge through social interaction (Van der Linden et al. 2000). Problem solving requires learners to monitor, control, and regulate their learning activities to improve performance (de Jong et al. 2005). In most CSCL contexts, problems are often complex and unstructured and have many possible solutions. In addition, it is common for learners to be no teacher present to provide regulatory guidance (Azevedo et al. 2004). Therefore, co-regulation is particularly important and necessary for successful collaborative learning (Winne et al. 2013). Learners have to co-regulate their learning processes to achieve a common understanding and shared goals. Moreover, the dynamics of interaction can be captured by co-regulation in collaborative learning.

Co-regulation of collaborative learning occurs when individuals' regulatory activities are supported, guided, or restricted by and with others in the group (Hadwin et al. 2011). Therefore, it is necessary for group members to be aware of each other's goals and progress, as well as to monitor, support, or coordinate one another's self-regulation. Co-regulation in CSCL involves learners regulating themselves as well as other group members (Chan 2012). To achieve this, group members have to monitor and track each other's progress during collaborative learning. Prior research has indicated that high-level co-regulation was most commonly preceded by a question or an explanation (Volet et al. 2009). Thus co-regulation can be triggered by questioning, prompting, or explanation.

Prior research has shown that a lack of regulation can hamper individual learning and group functioning (Barron 2000). If group members cannot regulate their learning, they may repeat their own opinions, ignore others' suggestions, or refuse others' proposals (Web 2013). Therefore, co-regulation is crucial for productive collaborative learning and for achieving shared goals. However, research on co-regulation has

received little attention in the CSCL field (Dillenbourg et al. 2009). Although a body of literature on regulated learning has emerged in recent years (Allal 2011; Hadwin et al. 2011; Volet and Vauras 2013), little is known about the behavioral patterns of co-regulation.

Previous studies indicated that the analysis of behavioral patterns in CSCL can shed light on the problems of knowledge building and coordination during collaboration (Hou et al. 2007; Hou 2010). The behavioral patterns analysis also can provide important findings with respect to the use of mobile phone as well as provide insights into improving the effectiveness of collaborative learning. The design of collaborative learning tasks or intervene also need to be evaluated based on behavioral patterns of collaborators so as to understand how the particular strategies can facilitate collaborative learning. Furthermore, the behavioral pattern analysis of co-regulation can also help us understand how group members regulate their behaviors during collaboration. It is also reported that the examination of the co-regulation behavioral patterns differences between high- and low-achievement groups can help to understand the positive factors leading to high achievement and the limitations of low-achievement groups (Hou & Wu 2011). An in-depth analysis of behavioral patterns could provide guidance for educators in understanding how different co-regulation behaviors contribute to high learning performance.

Recently, mobile devices have become more and more popular and been adopted to facilitate teaching and learning (Chen et al. 2008; Reychav and Wu 2015). Previous studies also indicated that mobile devices can promote information sharing (Zurita & Nussbaum 2004b) and coordinate task-oriented interaction (Boticki et al., 2011). Mobile computer supported collaborative learning (MCSCL) is characterized as the practice of meaning making in collaborative learning that is mediated by mobile computing (Zurita & Nussbaum, 2004a). Researchers have developed software that runs on mobile devices to facilitate collaborative learning (Cortez et al. 2005; Zurita & Nussbaum, 2004a). The findings of prior research also revealed that MCSCL can improve collaborative interactions, provide more learning opportunities, and enhance peers' real-time feedback (Huang et al. 2009; Roschelle et al. 2010). However, past studies lacked long-term observation of participants' co-regulation behaviors in the context of mobile collaborative learning. Therefore, the purpose of the present study is to explore the behavioral patterns of co-regulation in MCSCL.

## The present study

This study aims to explore the behavioral patterns of co-regulation to gain insight into how students regulate each other. The present study used lag sequential analysis (Bakeman and Gottman 1997) to examine the sequences of behavioral patterns observed during collaboration. Lag sequential analysis has been used in previous studies on digital learning (Hou et al. 2009). Compared to other analytical methods, such as self-report questionnaires or interviews, behavioral pattern analysis can provide insight into the actual co-regulatory behaviors in collaborative learning. Documentation of actual behaviors and analysis of behavioral patterns will be helpful in understanding why co-regulation achieves certain learning outcomes. Thus, the following research questions were addressed:

1. What are the behavioral characteristics of co-regulation in MCSCL?

2. How does co-regulation evolve over time in MCSCL?
3. Are there any differences in behavioral patterns of co-regulation between high- and low-achievement groups?

## Method

### Participants and tasks

The present study was conducted in a multimedia technology course worth three credits. The participants were 101 freshmen majoring in law or Chinese language and literature. Fifteen (15 %) were male, and 86 were female (85 %). The average age was 18. All of the participants were enrolled in the multimedia technology course for the first time. They all had prior experience about collaboration from previous courses.

### Procedures

Before the collaborative learning activity, all of the participants took a three-week multimedia technology course to learn how to make a Flash animation. Next, all of the participants were randomly assigned to twenty-three groups of four or five using a random allocation software. It is reported that the random assignment can create probabilistically equivalent groups (Louis et al. 2007). Every group need to complete the same collaborative learning task, namely creating a Flash animation within four weeks. This task was designed by the teacher ahead of time. In order to complete this task, every one need engage in a mobile collaborative learning activity via an instant message tool (QQ) by mobile phone. They can share information, pictures, group products, and communicate immediately via mobile phone anytime and anywhere. Every group collaborated freely via mobile phone. The teacher did not intervene students until they had some problems about the procedures. All of the discussion transcripts were recorded automatically by QQ. Thus it is feasible to analyze the co-regulation process based on the discussion transcripts of every group.

### Data analysis

This study used content analysis to analyze the discussion transcripts of the 23 groups. We revised the coding scheme proposed by Zheng et al. (2014) to analyze co-regulation behaviors. As shown in Table 1, the coding scheme for the analysis of co-regulation behavior included six dimensions. The goal orientation dimension consisted of one category: establishing tasks and setting goals (ES). The plan-making dimension consisted of two categories: making plans to reach the goal (MP) and negotiating the division of labor (ND). The enacting strategies dimension consisted of two categories: advancing and explaining solutions (AE) and coordinating conflicts (CO). The monitoring and controlling dimension consisted of three categories: monitoring or controlling group progress (MC), claiming (partial) understanding or comprehension failure (CC), and detecting errors or checking plausibility (DC). The evaluating and reflecting dimension consisted of two categories: evaluating current solutions (EV) and reflecting on the group's goals and progress (RE). The adapting metacognition dimension included one category: making adaptions to goals, plans, or strategies (MA).

Two coders skilled at content analysis independently coded all of the discussion transcripts according to the coding scheme. The analysis unit was the speaker's turn. If one

**Table 1** The coding scheme for co-regulation in CSCL

| Dimension | Category | Examples |
|---|---|---|
| Goal orientation | Establishing task demands and setting goals (ES) | "This task requires us to make Flash animation." |
| Making Plans | Making plans to achieve goals, including selecting strategies, setting timelines and so on (MP) | "We need to make a timeline so as to finish this task on time." |
| | Negotiating the division of labor (ND) | "Who will be responsible for searching for information?" |
| Enacting Strategies | Advancing and explaining solutions (AE) | "I have an idea. We can make this image by Photoshop first, then insert it into the Flash program." |
| | Coordinating conflicts (CO) | "You needn't argue anymore. I have solved this problem. " |
| Monitoring and controlling | Monitoring or controlling overall group progress (MC) | "How is it going? We only have one week left." |
| | Claiming (partial) understanding or Comprehension failure (CC) | "I don't understand how you made this animation." |
| | Detecting errors or checking plausibility (DC) | "I think we will have trouble with this solution." |
| Evaluating and reflecting | Evaluating current solutions (EV) | "The current plan is perfectly fine." |
| | Reflecting on the group's goals and progress (RE) | "Overall, we have reached the goal and finished the task on time." |
| Adapting Metacognition | Making adaptions to goals, plans, or strategies (MA) | "We need to adapt our strategies to make it better." |
| Off-topic | Not related to the learning tasks (OT) | "We will see a film this evening." |

speaker's turn demonstrated more than one type of co-regulation behavior, we coded it more than once. For example, if one group member said: "I don't understand how you made this animation. I think we will have some problems with this solution." Thus it will be coded as claiming (partial) understanding (CC) and detecting errors (DC). Cohen's kappa statistic was adopted to examine the analysis results. The Cohen's kappa was 0.82, indicating a good reliability. The two coders discussed and solved all of the discrepancies face-to-face.

To analyze the behavioral patterns of participants, lag sequential analysis (LSA) (Bakeman and Gottman 1997) was performed. LSA was used to examine the probability of behavioral occurrence (Hawks 1987). To conduct LSA, three steps were required. The first step was to calculate the frequency of each behavior code. The second step was to analyze the transfer matrix of behavioral frequency. The last step was to calculate the adjusted residuals (Bakeman and Gottman 1997). LSA has been widely used in previous studies to analyze behavioral patterns in simulation games (Hou 2015) and in online cooperative translation activities (Yang et al. 2015). In the present study, Generalized Sequential Querier (GSEQ) 5.1 was used to conduct LSA.

## Results

### RQ1: What are behavioral characteristics of co-regulation in MCSCL?

#### *Behavior frequency analysis*

To analyze the behavioral characteristics of co-regulation demonstrated by all of the participants, the frequency and distribution of the coded behaviors were calculated.

Table 2 shows the frequency and distribution of each type of behavior. The most frequent behavior was advancing and explaining solutions (AE, 30.63 %), followed by claiming (partial) understanding or comprehension failure (CC, 23.98 %), monitoring or controlling group progress (MC, 9.52 %), and evaluating current solutions (EV, 7.70 %). This indicated that students enacted strategies and monitored during co-regulation. However, coordinating conflicts appeared the least among all coded co-regulation behaviors. This revealed that group members had little conflict during collaboration. In addition, participants seldom made adaptions to goals, plans, or strategies.

#### *Sequential analysis of behavior*

To analyze the sequence of behavior transition for all participants during collaborative learning, the adjusted residuals were calculated using GSEQ 5.1. If the Z-value of a sequence was above 1.96, then the behavioral transition was considered statistically significant (Bakeman and Gottman 1997). Table 3 shows the adjusted residuals of all behavioral sequences. The rows represent the starting behaviors, and the columns represent the subsequent behaviors. As shown in Table 3, there were 16 behavioral sequences that reached the level of significance. To visualize the significant behavior sequences, a behavioral transition diagram was drawn, as shown in Fig. 1. The node denotes the behavior, the arrow denotes the transitional direction, the thickness of the arrow denotes the level of significance, and the number denotes the Z-value of the sequence.

As shown in Fig. 1, the participants' behavioral patterns were divided into five independent sections based on the sequential relationships between the behaviors. These five sections were ES-MC-MA (i.e., establishing task demands and setting goals, monitoring or controlling group progress, and making adaptions to goals, plans, or strategies), MP-CC-AE-DC (i.e., making plans to reach goals, claiming (partial) understanding or comprehension failure, advancing and explaining solutions, and detecting errors or checking plausibility), RE-EV (reflecting on the group's goals and progress, evaluating current solutions), ND (negotiating the division of labor), and OT (Off-topic). Overall, participants co-regulated each other by establishing goals, making plans, enacting strategies, monitoring and controlling, reflecting and evaluating, and adapting metacognition.

### RQ2: How does co-regulation evolve over time in MCSCL?

To examine how co-regulatory behavior evolves over time, the frequencies and sequence transitions of each type of behavior were analyzed in depth from week 1 to week 4. As shown in Table 4 and Fig. 2, the relative frequency of making plans increased from week 1 to week 4. In every week, advancing and explaining solutions (AE), monitoring or controlling group progress (MC), and claiming (partial) understanding or comprehension failure (CC) occurred the most frequently. These results indicated that participants enacted strategies and monitored the collaborative learning process. However, coordinating conflicts did not occur from week 1 to week 4. In the following section, the behavioral sequences from week 1 to week 4 are illustrated in detail.

#### *Behavioral sequences in Week 1*

In the first week, ES → MC, AE → DC, MP → EV, and RE → MP achieved significance (See Table 5 and Fig. 3). The behavioral path ES → MC indicated that when students established task demands and set goals, they tended to monitor and control the

**Table 2** Frequency and distribution of behavioral codes

| | ES | MP | ND | AE | CO | MC | CC | DC | EV | RE | MA | OT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Frequency | 110 | 260 | 129 | 1110 | 3 | 345 | 869 | 101 | 279 | 126 | 23 | 269 |
| Percentage | 3.04 % | 7.17 % | 3.56 % | 30.63 % | 0.08 % | 9.52 % | 23.98 % | 2.79 % | 7.70 % | 3.48 % | 0.63 % | 7.42 % |

**Table 3** Adjusted residuals

| | ES | MP | ND | AE | CO | MC | CC | DC | EV | RE | MA | OT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ES | 4.41* | −0.34 | −0.49 | −0.8 | −0.31 | 2.95* | −0.56 | 0.54 | −1.28 | −1.5 | −0.84 | −0.82 |
| MP | 0.5 | −0.16 | −1.14 | −4.14 | −0.48 | 1.79 | 5.53* | −1.67 | 0.47 | −0.37 | −1.31 | −1.8 |
| ND | −0.96 | −1.81 | 17.64* | −2.99 | −0.33 | 0.05 | 0.67 | −1.41 | −1.99 | −2.19 | −0.9 | −1.22 |
| AE | −0.42 | 0.17 | −3.06 | 0.69 | 0.09 | −1.57 | 4.12* | 5.66* | 0.95 | −3.5 | −0.36 | −5.89 |
| CO | −0.3 | −0.48 | −0.33 | 0.1 | −0.05 | 1.44 | −0.98 | −0.29 | −0.5 | −0.33 | −0.14 | 1.7 |
| MC | 1.27 | −1.24 | −0.39 | −0.91 | −0.56 | 0.45 | 3.25* | −2.28 | −1.18 | 0.93 | −1.53 | −1 |
| CC | −1.28 | 2.28* | −0.39 | 6.98* | 0.38 | 0.59 | −4.13 | −1.69 | −1.27 | −1.94 | 1.37 | −4.06 |
| DC | −1.19 | −0.88 | −1.42 | 4.58* | −0.29 | −2.21 | −1.25 | 1.94* | −0.31 | −1.39 | 1.79 | −1.36 |
| EV | −1.15 | 1.31 | −0.94 | 0.97 | −0.5 | 0.17 | −2.9 | −1.39 | 4.44* | 1.18 | 0.27 | −1.53 |
| RE | −0.35 | −1.37 | −2.17 | −2.55 | −0.33 | −1.7 | −2.06 | −1.92 | 2.56* | 19.32* | 1.47 | −2.51 |
| MA | 1.62 | −1.34 | −0.93 | −1.39 | −0.14 | 2.08* | 0.72 | −0.82 | 1.74 | −0.92 | 2.31 | −1.37 |
| OT | 0.39 | −0.31 | −0.89 | −6.52 | 1.71 | −0.83 | −4.68 | −0.58 | −3.03 | −2.2 | −0.52 | 25.6* |

*p < 0.05

learning process. When some students advanced and explained solutions, others tended to detect errors or check plausibility (AE → DC). In addition, students evaluated their plans after making them (MP → EV). Students also reflected in order to make good plans (RE → MP). These behaviors were reasonable because students needed to determine their goals and make plans in the first week. These behavioral paths were also desirable because the sequences were helpful for co-regulation during CSCL.

### *Behavioral sequences in Week 2*

Week 2 had eight significant behavioral sequences: ES → ES, ND → ND, MP → CC, AE → DC, AE → EV, RE → RE, MA → AE, and OT → OT (See Table 6 and Fig. 4). Other than the behavioral path AE → DC, this was the first time that these behavioral paths emerged. The behavioral path ES → ES indicated that when students established task demands and set goals, they tended to remain consistent in co-regulation behaviors.

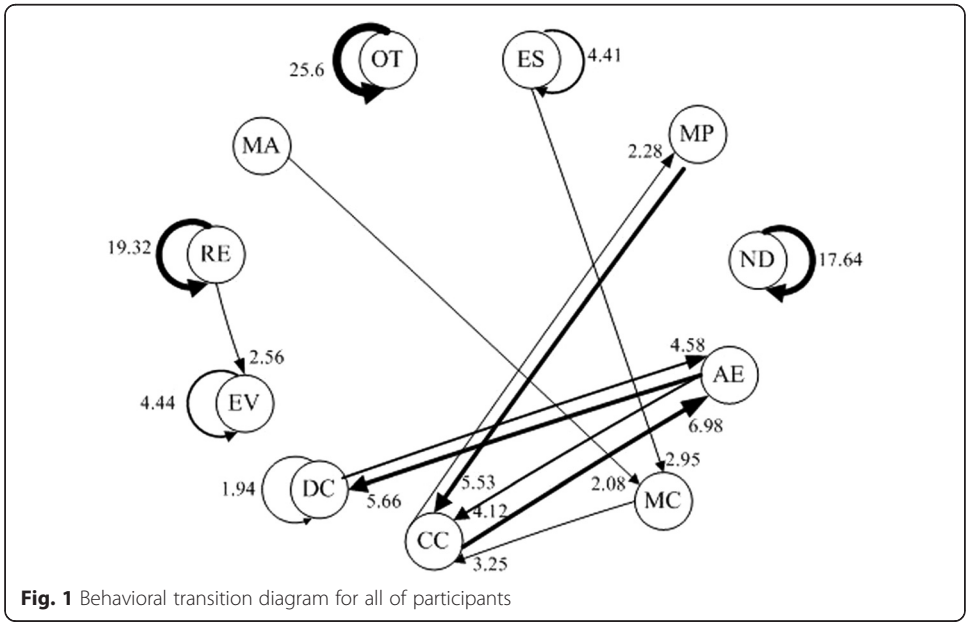


**Fig. 1** Behavioral transition diagram for all of participants

**Table 4** Frequencies of co-regulation behavior from week 1 to week 4

| | ES | MP | ND | AE | CO | MC | CC | DC | EV | RE | MA | OT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Week1 | 1 | 3 | 0 | 12 | 0 | 8 | 12 | 3 | 3 | 2 | 0 | 0 |
| | 2 % | 7 % | 0 % | 27 % | 0 % | 18 % | 27 % | 7 % | 7 % | 5 % | 0 % | 0 % |
| Week2 | 32 | 37 | 26 | 162 | 0 | 57 | 108 | 12 | 49 | 7 | 2 | 73 |
| | 6 % | 7 % | 5 % | 29 % | 0 % | 10 % | 19 % | 2 % | 9 % | 1 % | 0 % | 13 % |
| Week3 | 48 | 103 | 57 | 514 | 3 | 128 | 358 | 53 | 112 | 38 | 11 | 84 |
| | 3 % | 7 % | 4 % | 34 % | 0 % | 8 % | 24 % | 4 % | 7 % | 3 % | 1 % | 6 % |
| Week4 | 27 | 112 | 36 | 383 | 0 | 125 | 360 | 32 | 104 | 77 | 8 | 110 |
| | 2 % | 8 % | 3 % | 28 % | 0 % | 9 % | 26 % | 2 % | 8 % | 6 % | 1 % | 8 % |

The behavioral path ND → ND demonstrated that students negotiated the division of labor constantly. RE → RE indicated that students reflected continually. OT → OT revealed that when some students talked about unrelated topics, others continued to chat or talked about unrelated topics. The behavioral path MP → CC represented that when students made plans, they tended to monitor and claim partial understanding. The paths AE → DC and AE → EV denoted that when students advanced or explained solutions, others detected errors or evaluated the solutions. MA → AE indicated that when students made adaptions to goals, plans or strategies, others advanced or explained solutions.

#### *Behavioral sequences in Week 3*

In the third week, seven new behavioral sequences emerged: CC → AE, DC → AE, MC → CC, MC → RE, EV → EV, MA → ES, and OT → CO (See Table 7 and Fig. 5). The behavioral paths CC → AE and DC → AE revealed that when students claimed partial understanding and detected errors, they could advance new solutions and explain them. The paths MC → CC and MC → RE indicated that when students monitored the group's progress, they claimed partial understanding or reflected. EV → EV represented that when some students reflected, others also reflected. MA → ES denoted

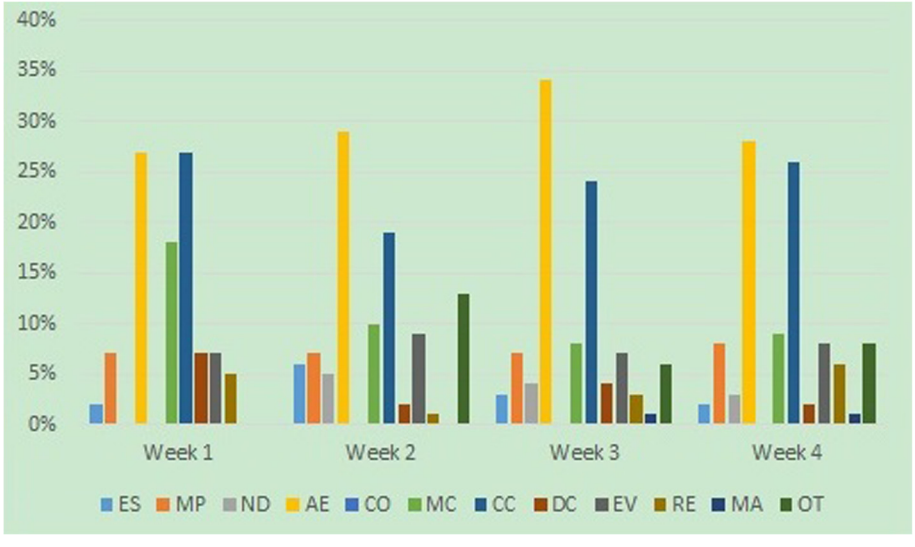


**Fig. 2** The trend of co-regulation behavior from week 1 to week 4

**Table 5** Adjusted residuals (Week 1)

| | ES | MP | ND | AE | CO | MC | CC | DC | EV | RE | MA | OT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ES | −0.17 | −0.3 | 0 | −0.61 | 0 | 2.6* | −0.65 | −0.3 | −0.3 | −0.24 | 0 | 0 |
| MP | −0.24 | −0.43 | 0 | −0.87 | 0 | −0.57 | 0.67 | −0.43 | 2.27* | −0.34 | 0 | 0 |
| ND | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| AE | 1.59 | 0.17 | 0 | −2.35 | 0 | −1.53 | 1.43 | 2.83* | 0.17 | −0.93 | 0 | 0 |
| CO | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| MC | −0.48 | −0.86 | 0 | 0.15 | 0 | −1.14 | 0.9 | −0.86 | 0.69 | 1.18 | 0 | 0 |
| CC | −0.56 | −1.01 | 0 | 1.41 | 0 | 0.92 | −0.51 | −1.01 | −1.01 | 0.9 | 0 | 0 |
| DC | −0.3 | −0.53 | 0 | 1.65 | 0 | 1.08 | −1.15 | −0.53 | −0.53 | −0.43 | 0 | 0 |
| EV | −0.3 | 1.7 | 0 | 0.29 | 0 | 1.08 | −1.15 | −0.53 | −0.53 | −0.43 | 0 | 0 |
| RE | −0.24 | 2.27* | 0 | 0.78 | 0 | −0.57 | −0.93 | −0.43 | −0.43 | −0.34 | 0 | 0 |
| MA | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| OT | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

*p < 0.05

that students reestablished task demands and revised goals when they made adaptions. The behavioral path OT → CO indicated that although students talked about irrelevant opics, they could return to establish task demands and set goals. These new behavioral sequences indicated that students could monitor, evaluate, reflect and make adaptations when they conducted collaborative learning. In addition, five behavioral sequences were the same as week 2: ES → ES, ND → ND, RE → RE, OT → OT, MP → CC. These results indicate that students continually establish task demands and set goals, negotiate the division of labor, reflect on the group's goals and progress, and discuss

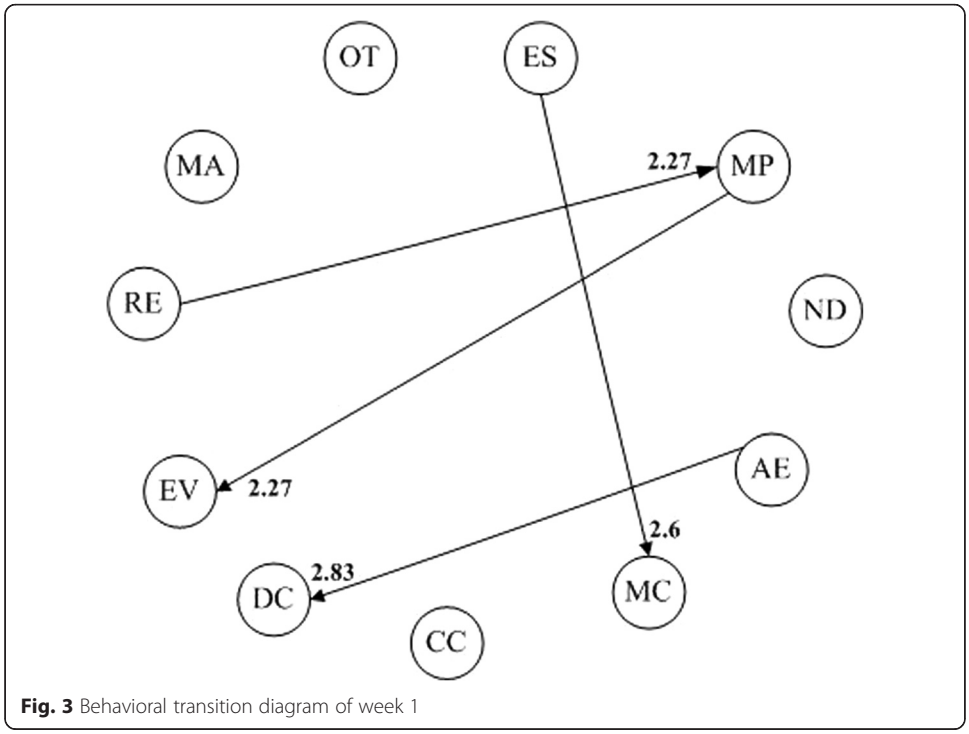


**Fig. 3** Behavioral transition diagram of week 1

**Table 6** Adjusted residuals (Week 2)

| | ES | MP | ND | AE | CO | MC | CC | DC | EV | RE | MA | OT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ES | 2.1* | −0.77 | −0.37 | 0.54 | 0 | 1.58 | −0.88 | 0.44 | −1.77 | −0.64 | −0.34 | 0 |
| MP | 0.17 | 1.14 | −1.36 | −1.98 | 0 | 1.81 | 2.28* | −0.91 | 0.53 | −0.7 | −0.37 | −1.37 |
| ND | −1.19 | −0.56 | 6.56* | −1.47 | 0 | 1.31 | 0.06 | −0.77 | −0.89 | −0.58 | −0.31 | −0.8 |
| AE | −0.5 | −0.68 | −2.47 | 1.36 | 0 | −1 | 1.6 | 2.89* | 2.86* | −1.71 | 0.65 | −3.68 |
| CO | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| MC | 0.69 | −1.03 | 0.19 | −0.47 | 0 | 0.5 | 1.37 | −1.19 | −1.03 | 0.34 | −0.48 | 0.17 |
| CC | −0.13 | 0.46 | 0.06 | 1.96 | 0 | −1.17 | −0.03 | 0.56 | −0.85 | −0.31 | 1.13 | −1.52 |
| DC | 0.51 | 1.38 | −0.78 | −0.95 | 0 | −1.09 | 1.22 | −0.52 | 0.95 | −0.4 | −0.21 | −0.51 |
| EV | −1.64 | 1.16 | 0.59 | 0.9 | 0 | 1.07 | −1.55 | −1.06 | 1.56 | 0.57 | −0.43 | −1.42 |
| RE | −0.62 | −0.72 | −0.59 | 0.81 | 0 | −0.83 | −1.31 | −0.4 | −0.83 | 13.25* | −0.16 | −1.04 |
| MA | −0.33 | −0.38 | −0.32 | 2.22* | 0 | −0.44 | −0.7 | −0.21 | −0.44 | −0.16 | −0.09 | −0.56 |
| OT | 0.79 | 0.1 | 0.38 | −2.69 | 0 | −1 | −3.17 | −1.35 | −1.94 | −1.03 | −0.55 | 9.94* |

*p < 0.05

unrelated topics. When students made plans, others also claimed partial understanding or comprehension failure.

#### *Behavioral sequences in Week 4*

In the last week, several new behavioral paths emerged, including AE → DC, AE → CC, CC → MP, RE → EV, MA → AE, MA → CC, and DC → MA (See Table 8 and Fig. 6). The behavioral sequence AE → DC indicated that when students advanced new solutions and explained them, others detected errors or checked for plausibility. AE → CC indicated that some students may claim partial understanding or comprehension failure when new solutions were advanced or explained. The behavioral path CC → MP revealed that when some students claimed partial understanding or comprehension failure, others made new plans for the collaborative learning task. The behavioral path RE → EV

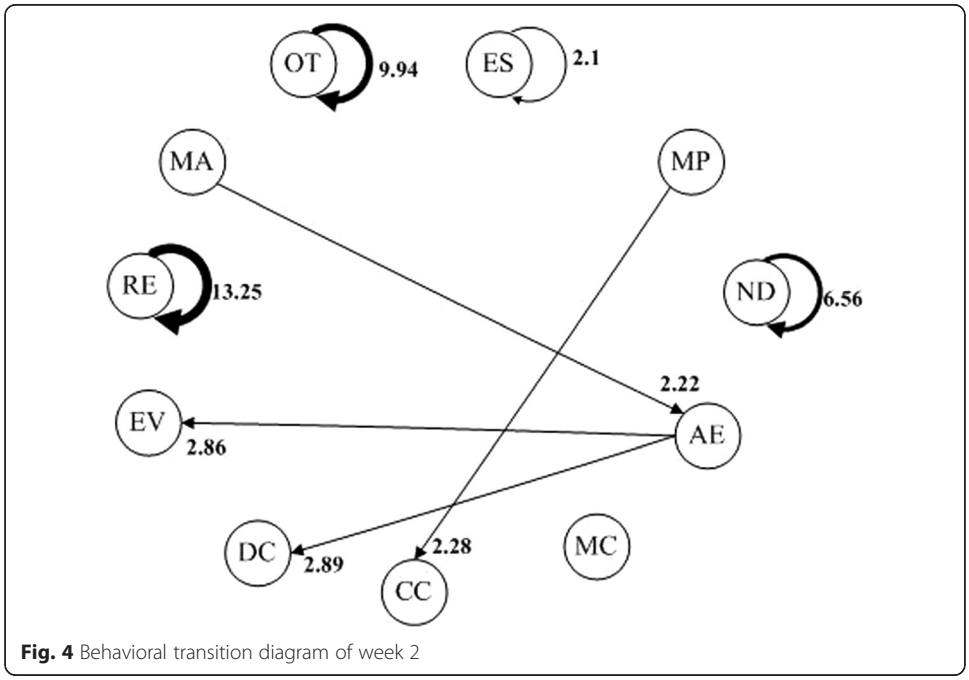


**Fig. 4** Behavioral transition diagram of week 2

**Table 7** Adjusted residuals (Week 3)

| | ES | MP | ND | AE | CO | MC | CC | DC | EV | RE | MA | OT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ES | 3.05* | −0.15 | −0.62 | −2.6 | −0.32 | 1.03 | 1.92 | 1.03 | −0.34 | −0.18 | −0.61 | −1.07 |
| MP | 0.55 | −1.19 | −0.99 | −1.7 | −0.47 | 0.88 | 3.55* | −0.9 | 1.3 | −1.01 | −0.9 | −2.09 |
| ND | −1.36 | −1.54 | 12.69* | −2.7 | −0.35 | 0.09 | 1.09 | −0.75 | −2.19 | −1.23 | −0.66 | −0.1 |
| AE | 0.51 | 1.17 | −1.49 | −0.31 | −0.03 | −0.23 | 1.85 | 2.02 | −0.7 | −1.64 | 0.15 | −2.72 |
| CO | −0.25 | −0.38 | −0.28 | 0.47 | −0.06 | −0.43 | −0.79 | −0.27 | −0.4 | −0.23 | −0.12 | 2.74 |
| MC | 0.08 | 0.12 | −1.36 | −1.12 | −0.53 | 0.4 | 2.51* | −1.27 | −0.92 | 2.27* | −1.02 | −0.86 |
| CC | −0.57 | 0.54 | −0.38 | 5.66* | 0.4 | 0.74 | −3.8 | −1.47 | −1.24 | −2.24 | 0.29 | −1.47 |
| DC | −1.29 | −1.98 | −1.45 | 3.64* | −0.33 | −1.72 | −1.78 | 1.64 | 0.59 | −0.26 | 1.02 | 0.07 |
| EV | −0.78 | 1.76 | −0.61 | 0.22 | −0.49 | −1.91 | −2.18 | −0.5 | 3.99* | 0.79 | 0.21 | 0.36 |
| RE | −0.06 | −0.25 | −1.18 | −1.43 | −0.27 | −0.59 | −1.34 | −1.15 | 1.54 | 10.04* | 1.48 | −0.71 |
| MA | 2.95* | −0.9 | −0.66 | −1.76 | −0.15 | 1.17 | 0.27 | −0.64 | 1.35 | −0.53 | 3.25 | −0.81 |
| OT | −1.01 | −0.75 | −0.68 | −3.96 | 2.08* | 0.37 | −1.32 | 1.22 | −0.98 | −0.06 | −0.81 | 12.41* |

*p < 0.05

demonstrated that students evaluated the current solutions when they reflected on group goals and progress. The behavioral paths MA → AE and MA → MC showed that when students made adaptions to goals, plans, or strategies, they could advance new solutions or monitor group progress. DC → MA indicated that students made adaptations after they detected errors. Therefore, all of these behavioral sequences revealed that in this week, the main task was to reflect, evaluate and revise the collaborative learning products. In addition, students provided new solutions or monitored group progress. All of these behavioral paths were desirable because they were necessary to achieve successful co-regulation and productive collaborative learning.

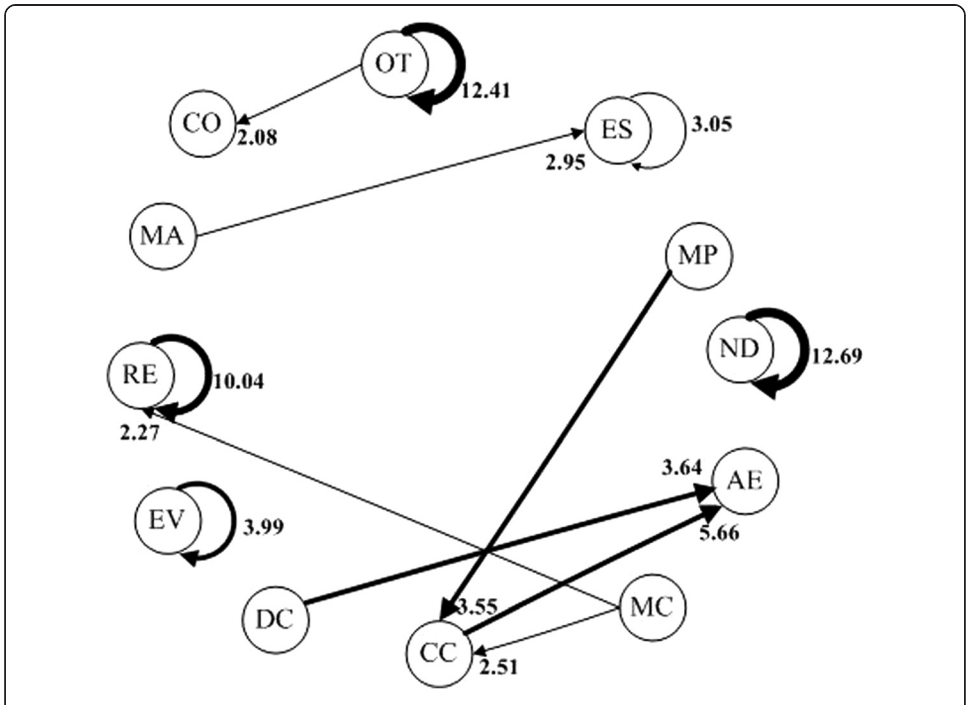


**Fig. 5** Behavioral transition diagram of week 3

**Table 8** Adjusted residuals (Week 4)

| | ES | MP | ND | AE | CO | MC | CC | DC | EV | RE | MA | OT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ES | 0.68 | 0.59 | 0.37 | 1.5 | 0 | 1.79 | −1.83 | −0.82 | −0.04 | −1.29 | −0.35 | −0.85 |
| MP | −0.09 | 0.39 | 0.08 | −3.31 | 0 | 1.11 | 3.28* | −1.06 | −0.91 | 0.3 | −0.73 | 0 |
| ND | 1.66 | −0.51 | 8.74* | −0.67 | 0 | −0.66 | −0.49 | −0.93 | 0.22 | −1.47 | −0.4 | −1.15 |
| AE | −1.03 | −0.62 | −1.48 | 0.83 | 0 | −0.83 | 2.81* | 4.75* | 0.2 | −2.54 | −0.63 | −3.55 |
| CO | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| MC | 1.13 | −0.66 | 0.49 | 0.36 | 0 | −0.63 | 2.02* | −1.81 | −0.84 | −0.4 | −0.78 | −1.03 |
| CC | −0.79 | 2.43* | 0.35 | 3.43* | 0 | 0.18 | −2 | −0.94 | 0.06 | −1.34 | 0.41 | −3.31 |
| DC | −0.8 | −0.38 | 0.2 | 3.22* | 0 | −1.15 | −0.19 | 1.47 | −1.64 | −1.41 | 2.31* | −1.7 |
| EV | 0.82 | −0.4 | −1.69 | 0.26 | 0 | 1.52 | −1.06 | −0.93 | 2.12* | 0.59 | 0.87 | −1.57 |
| RE | 0.49 | −1.76 | −1.45 | −2.36 | 0 | −1.52 | −1.85 | −1.39 | 2.82* | 12.69* | 1.2 | −2.21 |
| MA | −0.4 | −0.84 | −0.46 | −1.76 | 0 | 2.86* | 1.51 | −0.44 | 0.52 | −0.7 | −0.19 | −0.84 |
| OT | −0.07 | −0.28 | −1.14 | −3.88 | 0 | −0.23 | −3.37 | −1.04 | −2.37 | −2.24 | −0.73 | 17.98* |

*p < 0.05

### RQ3: Are there any differences in co-regulation behavioral patterns between the high- and low-achievement groups?

To address the third research question, LAS was conducted to analyze the differences in behavioral patterns between the high-achievement groups and the low-achievement groups. The final score of the Flash animation created was the achievement of each group. The Flash animation of each group was rated by the other groups and by the teacher. The final score was equal to the average scores of the other groups and the teacher. We selected the top six groups as the high-achievement groups and the last six groups as the low-achievement groups. All behavioral codes of these 12 groups were analyzed by GSEQ 5.1.

Table 9 shows the frequencies of co-regulation behavior of the low-achievement groups and high-achievement groups. It was very clear that the high-achievement

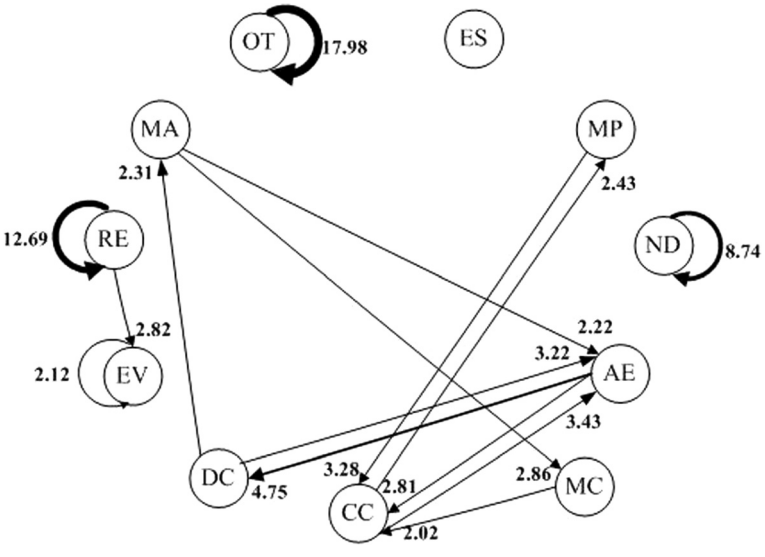


**Fig. 6** Behavioral transition diagram of week 4

**Table 9** Frequencies of co-regulation behavior of the low-achievement and high-achievement groups

| | ES | MP | ND | AE | CO | MC | CC | DC | EV | RE | MA | OT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| low-achievement groups | 10 | 40 | 23 | 151 | 0 | 37 | 126 | 12 | 52 | 11 | 2 | 46 |
| | 1.96 % | 7.84 % | 4.51 % | 29.61 % | 0 | 7.25 % | 24.71 % | 2.35 % | 10.20 % | 2.16 % | 0.39 % | 9.02 % |
| high-achievement groups | 42 | 77 | 45 | 365 | 0 | 119 | 255 | 23 | 90 | 49 | 12 | 48 |
| | 3.73 % | 6.84 % | 4.00 % | 32.44 % | 0 | 10.58 % | 22.67 % | 2.04 % | 8.00 % | 4.36 % | 1.07 % | 4.27 % |

groups demonstrated a higher proportion of behaviors in terms of establishing task demands and setting goals (ES), advancing and explaining solutions (AE), monitoring or controlling group progress (MC), reflecting on group goals and progress (RE), and making adaptations (MA). The low-achievement groups demonstrated a higher proportion of behaviors including making plans (MP), negotiating the division of labor (ND), claiming partial understanding (CC), detecting errors (DC), and off-topic discussion (OT). The results also indicated that coordinating conflicts (CO) did not appear in either the low-achievement groups or the high-achievement groups.

To examine the differences in co-regulation behavioral patterns between the low-achievement groups and high-achievement groups, the adjusted residuals were calculated by GSEQ 5.1, as shown in Table 10 and Table 11. In addition, the behavioral transition diagrams of the low-achievement groups and high-achievement groups were constructed, as shown in Figs. 7 and 8. The results indicated that there were 12 statistically significant behavioral paths in the low-achievement groups (ND → ND, RE → RE, EV → EV, OT → OT, AE → CC, DC → CC, EV → RE, AE → AE, DC → DC, ES → ES, MA → CC, MP → CC) and 13 statistically significant behavioral paths in the high-achievement groups (ND → ND, RE → RE, EV → EV, OT → OT, AE → CC, DC → CC, EV → RE, AE → DC, DC → AE, CC → AE, ES → MC, MA → MC, MA → MA). Eight behavioral paths, namely, ND → ND, RE → RE, EV → EV, OT → OT, AE → CC, DC → CC, MA → CC and EV → RE, occurred in both groups.

Five different behavioral paths emerged between the low-achievement groups and high-achievement groups. First, the behavioral path AE → DC occurred in the high-achievement groups, while the behavioral path AE → AE appeared in the low-achievement groups. This indicated that students in the high-achievement groups advanced or explained the solutions and then proceeded to detect errors or check the plausibility. Conversely, students in the low-achievement groups repeatedly advanced or explained the solutions. Second, the behavioral path DC → AE occurred in the high-achievement groups, whereas the behavioral path DC → DC appeared in the low-achievement groups. This result revealed that students in the high-achievement groups advanced or explained the solutions after they detected errors,

**Table 10** Adjusted residuals (low-achievement groups)

| | ES | MP | ND | AE | CO | MC | CC | DC | EV | RE | MA | OT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ES | 4.13* | 0.27 | −0.7 | 0.02 | 0 | −0.86 | −0.37 | −0.5 | −0.03 | −0.48 | −0.14 | 0.1 |
| MP | −0.94 | 0.56 | 0.14 | −2.49 | 0 | 0.2 | 2.28* | −1.03 | 0.47 | 1.27 | −0.29 | −0.37 |
| ND | −0.68 | −0.57 | 8.35* | −0.26 | 0 | −0.42 | −1.76 | −0.75 | 0.52 | −0.72 | −0.21 | −1.52 |
| AE | −0.69 | −0.61 | −1.81 | 2.56* | 0 | −0.46 | 2.08* | 1.53 | −0.82 | −1.53 | −0.65 | −3.64 |
| CO | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| MC | 0.35 | −1.16 | 1.12 | 0.49 | 0 | 1.08 | −0.8 | −0.97 | −0.97 | −0.93 | −0.28 | 1.63 |
| CC | 0.38 | 0.9 | −0.84 | 1.53 | 0 | 0.23 | −0.3 | −0.66 | −0.98 | −0.51 | 1.74 | −1.22 |
| DC | −0.5 | −1.02 | 0.63 | −1.64 | 0 | −0.94 | 2.7* | 3.29* | −0.23 | −0.52 | −0.16 | −1.11 |
| EV | −1.06 | 0.63 | −0.92 | −0.61 | 0 | 0.37 | −2.24 | −0.19 | 4.33* | 2.97* | −0.33 | −1.33 |
| RE | −0.45 | 0.27 | −0.7 | 0.72 | 0 | −0.86 | −1.11 | −0.5 | 1.02 | 3.9* | −0.14 | −1.01 |
| MA | −0.2 | −0.41 | −0.31 | −0.92 | 0 | −0.38 | 2.45* | −0.22 | −0.48 | −0.21 | −0.06 | −0.45 |
| OT | 1.21 | 0.25 | −1.56 | −2.94 | 0 | 0.55 | −1.96 | −0.1 | −1.9 | −1.06 | −0.32 | 10.1* |

*$p < 0.05$

**Table 11** Adjusted residuals (high-achievement groups)

| | ES | MP | ND | AE | CO | MC | CC | DC | EV | RE | MA | OT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ES | −1.3 | 0.69 | 1.05 | −1.24 | 0 | 3.98* | −0.19 | 2.37* | −1.38 | −1.41 | −0.69 | −1.4 |
| MP | 0.69 | 0.79 | −1.26 | −2.04 | 0 | 0.81 | 2.14 | −0.48 | −0.08 | −1.37 | −0.95 | 0.99 |
| ND | −0.55 | −1.26 | 10.22* | −1.52 | 0 | −1.32 | 1.03 | 0.08 | −1.47 | −1.47 | −0.71 | −0.7 |
| AE | 1.11 | −0.03 | −1.52 | −0.55 | 0 | −1.79 | 2.66* | 2.02* | 1.09 | −1.55 | −1.19 | −1.78 |
| CO | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| MC | 1.8 | 0.31 | −0.39 | −1.41 | 0 | 0.88 | 1.64 | −0.3 | 0.51 | −1.52 | −1.2 | −1.49 |
| CC | −1.3 | 0.75 | −0.41 | 4.85* | 0 | −1.15 | −2.9 | −0.59 | −0.86 | −0.71 | 1.6 | −1.35 |
| DC | 0.15 | −1.32 | −0.99 | 4.72* | 0 | −0.95 | −2.12 | −0.7 | −0.66 | −1.04 | 1.54 | −1.03 |
| EV | −1.35 | −0.46 | −0.3 | 0.78 | 0 | 1.45 | −1.03 | −1.42 | 2.01* | −0.46 | 0.06 | −0.97 |
| RE | 0.15 | −1.93 | −1.45 | −1.78 | 0 | −0.45 | −1.71 | −1.03 | −0.47 | 14.35* | 0.7 | −1.5 |
| MA | −0.69 | −0.95 | −0.71 | −0.57 | 0 | 2.64* | −0.49 | −0.5 | 1.1 | −0.75 | 2.46* | −0.74 |
| OT | 0.15 | 1.57 | −1.45 | −3.67 | 0 | −0.45 | −1.36 | −1.03 | −1.01 | −0.79 | 0.7 | 13.79* |

*p < 0.05

whereas the students in the low-achievement groups constantly detected errors or checked the plausibility of solutions. In addition, the behavioral path CC → AE appeared in the high-achievement groups only; this indicated that students could advance or explain the solutions after they claimed comprehension failure. Third, the behavioral path ES → MC occurred in the high-achievement groups, while the behavioral path ES → ES appeared in the low-achievement groups. This indicated that students in the high-achievement groups tended to monitor or control the progress of the group after they established the goals, whereas students in the low-achievement groups repeatedly established goals. Fourth, the behavioral paths MA → MC and MA → MA appeared in the high-achievement groups, while the behavioral path MA → CC occurred in the low-achievement groups. This finding indicated that students in the high-achievement groups tended to monitor the group's process after they made adaptations, while students in the low-achievement

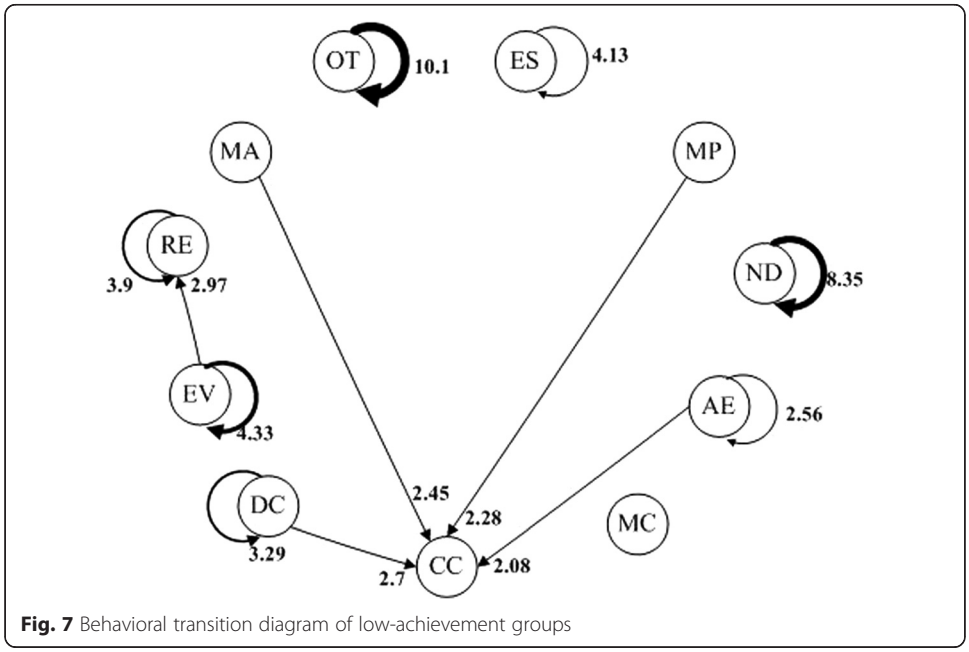


**Fig. 7** Behavioral transition diagram of low-achievement groups

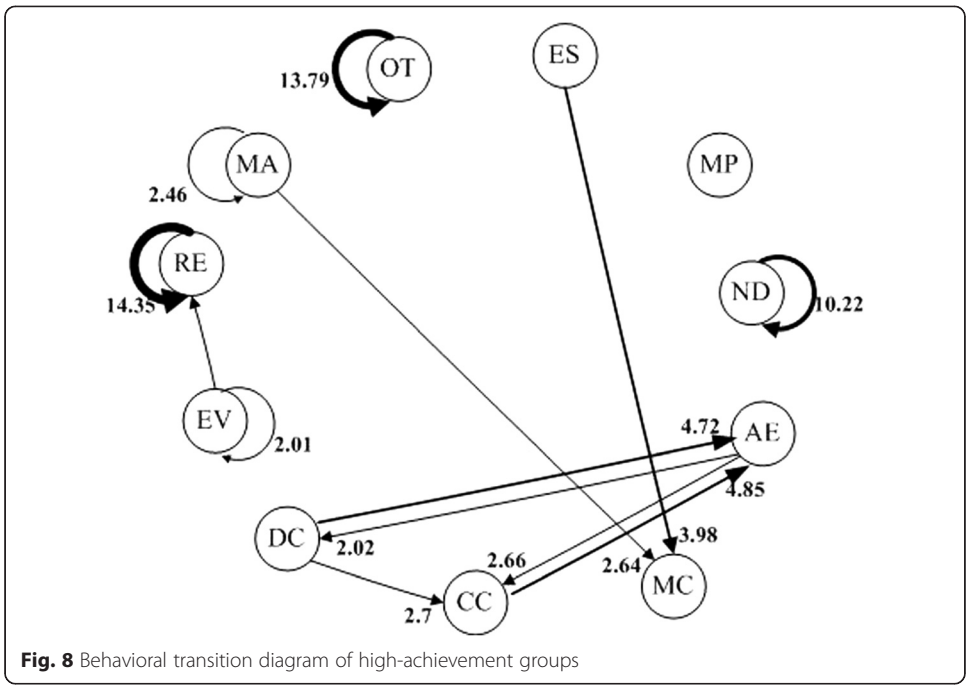


**Fig. 8** Behavioral transition diagram of high-achievement groups

groups tended to claim comprehension failure after they made adaptations. Finally, the behavioral path MP → CC only appeared in the low-achievement groups. This indicated that students in the low-achievement groups had more comprehension failure or partial understanding of the subject matter after making a plan, while students in the high-achievement groups gained a better understanding of the new plan.

## Discussion

This study used content analysis and lag sequential analysis to understand the behavioral patterns of co-regulation in a MCSCL context. We examined the behavioral characteristics and patterns of co-regulation as well as differences between the high- and low-achievement groups. The results indicated that different types of co-regulation behaviors occurred, such as establishing goals, making plans, enacting strategies, monitoring and controlling, reflecting and evaluating, and adapting metacognition. This finding was consistent with Lajoie and Lu (2012) who reported that different co-regulation behaviors including planning, orienting, monitoring, and evaluating occurred in two collaborative learning conditions. Previous studies also revealed that these co-regulation behaviors are needed for achieving productive and effective outcomes (Winne and Hadwin 2008; Zimmerman 2006). Processes of co-regulation can also enhance the building of common ground and shared understating (Saab 2012). These co-regulation behaviors were promoted and facilitated by mobile devices because of their high degree of portability (Sung et al. 2010). Students can use mobile phone to co-regulate their behaviors anytime and anywhere.

The findings also revealed that different behavioral paths emerged from week 1 to week 4. At first, students primarily established goals and made plans; then, they advanced new ideas and detected errors or checked feasibility. In week 3, students began to monitor group progress and evaluate current solutions. In the last week, students

made adaptations to goals, plans, or strategies when they detected errors. This result conforms to the previous study that different behavioral sequences demonstrated in different collaborative learning phases (Yang et al. 2015).

In addition, there were differences in behavioral patterns between the low-achievement groups and the high-achievement groups. These findings are in line with previous reports that the behavioral sequences between high-score groups and low-score groups had different characteristics (Hou 2015; Yang et al. 2015). Students in high-achievement groups demonstrated a high proportion of co-regulatory behaviors, including establishing task demands and setting goals, advancing and explaining solutions, monitoring or controlling group progress, reflecting on group goals and progress, and making adaptations. These behaviors were helpful for productive collaborative learning (Ucan and Webb 2015). Establishing task demands and setting goals contributed to building a shared understanding of the collaborative learning task. Advancing and explaining solutions facilitated the co-construction of knowledge among group members. Monitoring or controlling group progress helped students clarify their shared understanding and sustained the ongoing collaborative learning process. Reflecting and making adaptations enhanced the regulatory process to reach a consensus on shared understanding. Conversely, students in the low-achievement groups demonstrated more comprehension failure than the high-achievement groups when new solutions were proposed or explained. In addition, students in the low-achievement groups also repeatedly performed the same behavior, which was consistent with previous studies (Yang et al. 2015; Hou 2015). This may resulted from the limited previous knowledge or co-regulation skills of the low-achievement groups. However, students in the high-achievement groups changed their behaviors to achieve better co-regulation. Similar findings have been found by Saab (2012) that co-regulation was positively related to group performance.

Regarding the implications of this study, the findings illustrate how collaborative learning groups engage in co-regulation over time in a MCSCL context. First, this study could be useful when designing prompts or scripts to facilitate co-regulation in MCSCL environments. The aforementioned behaviors could be utilized to guide group members during co-regulation. Second, another important implication is the need for more MCSCL research on the actual behaviors of co-regulation. The actual performance of behaviors is more authentic and meaningful than self-reported behaviors. Third, the temporal aspects were also very crucial for understanding the process of co-regulation. Fourth, the present study provided insight into the behavioral pattern of co-regulation, which may be helpful for instructional designers to gain a better understanding of regulatory behaviors. It may also be useful for researchers to identify the relationships between behavioral patterns and learning outcomes. Fifth, the lag sequential analysis method visualized the behavioral sequences by a behavioral-transition diagram, which is useful to understand the differences in behavioral transitions. Finally, the present study highlighted the importance of fostering co-regulatory abilities during collaborative learning.

There were several limitations in the present study. First, we only analyzed participant behaviors. Future studies can analyze learners' cognition, emotion, social interactions, and knowledge construction combined with their behavioral patterns. Second, only co-regulation behaviors were investigated in the present study. Future studies

could explore the characteristics of socially shared regulation in the MCSCL context. Third, content of contributions was ignored when coding discussion transcripts. Thus, cautions should be made when interpreting results. Future studies will also analyze the process of knowledge building. Finally, this study was conducted without any intervention. Future studies could compare the behavioral differences before and after an intervention.

**Competing interests**
The authors declare that they have no competing interests.

**Authors' contributions**
All authors read and approved the final manuscript.

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