Similar Learning Performance with Different Regulation Process in Collaborative Problem Solving Learning Activities

Wenting Sun[1], Jiangyue Liu[2], Xiaoling Wang[3]

Humboldt-Universität zu Berlin, Germany[1]
Suzhou University, China[2]
Zhejiang Normal University, China[3]

Abstract

As a mode of computer-supported collaborative learning (CSCL), Collaborative Problem Solving (CPS) fosters the development of learners' metacognition, collaboration, and cognitive skills [1]. However, the mere presence of technology does not guarantee successful collaboration, as the effectiveness of CSCL involves complex interactions with various variables [2]. One significant variable is Socially Shared Regulation (SSR). Preliminary results indicate that the multifaceted aspects of SSR may relate to different learning performances [3]. Therefore, research is needed to adopt a process-oriented perspective on time-bound evaluations in collaborative learning to gain insights into the dynamics of SSR [4].
This empirical study investigates the contributions of speech recordings and process mining to promoting successful CPS learning assisted by CSCL scripts in authentic classrooms. From the perspective of SSR, the study presents regulator profiles of groups based on their adoption ratio of deep-level SSR behaviours and task completion scores during an authentic engineering practice course. Group oral dialogues were collected, and methods combining clustering and process mining were employed.
The results identified three regulation profiles: "high deep-SSR-behaviours-ratio high task-completion" (Cluster 1), "low deep-SSR-behaviours-ratio high task-completion" (Cluster 2), and "high deep-SSR-behaviours-ratio low task-completion" (Cluster 3). By examining Clusters 1 and 2 (which shared similar task performance), this study further explored the dynamic characteristics of groups' SSR behaviours to explain the emergence of an adaptive, group-organizing system during the authentic CPS process assisted by CSCL scripts. These findings offer educators and designers valuable strategies for fostering effective CPS and SSR dynamics in real-world CPS environments, ultimately improving the overall effectiveness of CPS.

Keywords: *Collaborative problem solving, Group dynamics, Process mining, Socially shared regulation,*

1. Introduction

To face complicated problems in the digital era, collaboratively solving problems (CPS) is one important part of the workspace. As one of the computers supported collaborative learning (CSCL) modes, CPS promotes the development of learners' metacognition, collaboration, and cognitive skills [1]. However, the mere presence of technology does not necessarily lead to successful collaboration because the effectiveness of CSCL is a complex set of interactions with other variables [2]. As one of the common approaches to facilitate CPS, collaborative scripts structure interactions by defining the cluster and sequences of activities in different grain sizes [5]. CSCL scripts lead to significantly higher levels of dialogic acts positively relating to higher learning performance in CPS [6]. During the process, individuals achieve deep understanding by decreasing transaction costs during CPS [7].
To investigate how individuals interdependently regulate activities in collaborative learning to achieve shared learning goals, a concept named Socially Shared Regulation (SSR) has emerged [8]. Considering the multifaceted aspects of SSR, though the frequency of metacognitive interaction at the group level played a role in individual learning achievement [9], potential differences in the depth of SSR still need more research rather than just the frequency of occurrence [3]. More research about the sequential patterns of SSR in collaborative learning and successful collaborative learning is needed [10], particularly the sequential analysis focusing on the entire flow of the problem-solving process [11]. To our best knowledge, detailed analysis on evaluations of multifaceted aspects of SSR in CPS learning in authentic practice course remains understudied.

Therefore, this study aims to provide in-depth analysis of how and when different facets of SSR are adopted, identify critical changes over time regarding learners' engagement in SSR skills and strategies, and suggest adaptive scaffoldings and learning analysis design.

2. Related Works

2.1 Collaborative Problem Solving and CSCL Scripts

To deeply explore essential activities, accumulating research in engineering education has stressed the value of learners' conversation during CPS. For example, [12] examined how the distribution of individuals' verbal episode contributions to teamwork relates to their team performance and individual success. In engineering classrooms, external scaffoldings are required to structure a course process as a collaborative process given the difficulty of handling open ended problems in CPS [13]. From the perspective of effects on learning performances, CSCL scripts not only benefit domain learning but also collaboration skills [6, 14]. CSCL scripts can enable a more fine-grained analysis of how regulation evolves across the individual and group levels [15]. The scripted phases initiated by CSCL scripts provide time and space for groups to evaluate their strategies and rethink the challenges they are facing [16]. However, the effects of the CSCL scripts are influenced by several factors.

2.2 Socially Shared Regulation

As argued by [17] regarding education as a complex system, the whole of a complex system is not merely the sum of parts. Similarly, group performance in CPS is not simply the sum of individual activities. Successful group performance is the result of complex interactions among several variables. Tentative results indicate that the multifaceted aspects of SSR may relate to different learning performances. For example, the frequency of SSR appears to be significantly positively related to students' immediate knowledge gains when SSR functions to activate collaborating learning through new activities and to challenge ongoing interactions to find an alternative direction [3]. Research by [18] suggests that it is not the amount or frequency but the interplay of metacognitive regulation's forms and foci that differentiates less successful from more successful collaborative learning. These studies emphasize that exploring the dynamics of SSR during collaborative learning could help unravel the complex collaborative learning process [19].

2.3 Regulation Profiles and Process Mining

Research is needed to adopt a process-oriented perspective on time-bound evaluations in collaborative learning to gain insights into the dynamics of SSR [4, 19]. Existing research conducted in formal face-to-face learning contexts has focused on the emergence of SSR progressed over time [20]. Results show that group-level regulation emerges more frequently in joint interactions. However, no information about the relationship between group performances and multifaceted aspects of SSR in the collaborative progress, and none of them has been conducted in authentic face-to-face engineering CPS practice courses.

In summary, several research gaps still exist regarding sequential SSR behaviours in the context of CPS combined with CSCL scripts in formal face-to-face engineering practice settings. Based on these gaps, two research questions (RQs) were proposed in this study:

RQ1: What SSR group profiles can be detected based on groups' adoption ratio of deep-level SSR behaviours and task completion scores during authentic engineering classroom activities?

RQ2: How are the SSR group profiles related to groups' SSR processes during CPS assisted by CSCL scripts?

3. Methods

3.1 Context and Participants

36 undergraduates from a public Chinese university participated, forming 18 dyads groups. Supported by CSCL scripts, students worked together to take turns being the IP sender and receiver using Internet Control Message Protocol (ICMP) package. Group members were required to use their own computers to take turns being the IP sender and receiver. Unlike in the computer lab where the computer hardware and software are standardized, the hardware and software of students' own

computers varied greatly due to different usage environments. To complete the tasks, students faced several challenges in both computer operation and group management. These challenges included visualization software configuration issues, operating system differences, network environment constraints, and uncertainty in experimental data. Resource sharing and the balance of individual learning and group work also impacted the task completion. The CSCL script used can be seen in Table 1. The CSCL script was produced based on the general self-regulation learning model, discussion patterns code schemes in collaborative engineering courses [21], and the instructor's 20 years of teaching experience.

Table 1. CSCL scripts for student groups.

Planning phase	1. Tasks explaining and analysing: Clarify the definition and requirements of the tasks.
	2. Function analysing: To solve the given task, what functions need to be identified?
	3. Design considering: To form solutions, what components need to be considered?
	4. Prior examples: Any experience in watching others' operations to solve similar tasks?
	5. Prior operating experience: Any self-experienced operations to solve similar tasks?
	6. Given resources: Resources available and accessible for the task.
Performance and reflection phase	1. Solution generation: Operation plans.
	2. Operation progress: Whether all operation actions have been completed?
	3. Operation results: Whether the task has been completed following the operation plan?
	4. Phenomenon occurred: What signals or warnings appeared when solving the subtasks successfully or not?
	5. Discussion and reflection: What reasons led to or promoted the operation plan successfully or not?

3.2 Data Collection and Analysis

Group oral dialogues were recorded and manually transcribed into text data for content analysis.
SSR code scheme: The coding instrument from [22] was employed as the initial version of the code schemes. During transcription, additional SSR phases were identified. The final SSR code scheme included Orientation, Planning, Support strategies, Monitoring, as well as Evaluation and reflection dimensions of SSR, which consisted of related strategies and further activities. Due to space limitation, we further explain one of the dimensions, Planning (see Table 2; the content in italics is new content added in this study). The Planning dimension encompassed problem solving solutions either at the commencing phase or fine-tuning solutions based on operation results. In this dimension, the original term "Formulating problem solving plan" under "Interim Planning" were divided into five new planning activities. In line with the typology of low and deep approaches to learning [22], SSR behaviours that involve new planning building, spontaneities actions, reflection, or explanation were regarded as deep level because these behaviours integrated task content, execution activities, group members' construction of knowledge, and meaningful thinking. All code schemes can be accessed at the OSF link: https://osf.io/pd8s7/?view_only=ab687610de7147f1bfaa6c917d449af4

Table 2. Code schemes of deep and low levels of SSR (examples of one dimension).

Dimension	Code	Levels	Activities	*Descriptions*
Planning	Planning in advance	Low	Formulating problem solving	A general starting solution for the group task only appears at the

			plan (planning in advance)	beginning.
		Deep	Selecting problem solving plan (planning in advance)	Few general alternative starting solutions for the group task only appear at the beginning.
	Interim Planning	*Low*	*Formulating problem solving plan repeated (interim planning)*	The previous operation is performed again without changing the operating variables. The purpose is to check whether there are accidental phenomena in the previous operation.
		Deep	*Formulating problem solving plan new (interim planning)*	To test whether the desired operation result will be obtained after changing an operation variable.
		Deep	*Peers' formulating problem solving plan new (interim planning)*	New operation solution produced by peers from other groups after asking for help.
		Deep	*Teacher's formulating problem solving plan new*	New operation solution produced by teacher after asking for help.
		Deep	Selecting problem solving plan	Few alternative operation solutions produced during the task.
		Deep	*Questioning the problem solving plan*	Express confusion to group members' operation solutions.

Task completion evaluation. As a performance result of groups, task completion was measured in several aspects, including whether learners use their own computers (some students' computers had problems, and they borrowed computers from other groups) (one point for one group member's computer), software installation readiness (one point for each computer), the completion of subtasks (one point for one subtask, five subtasks in total), and the different detailed helps asked from other groups.

After data pre-processing and analysis, k-means cluster analysis was performed to cluster the group SSR behaviours. K-means is an unsupervised machine-learning algorithm that assigns data points to clusters centers (centroids) based on similarity, which has been widely adopted [3]. Considering the task completion duration of different groups was not equal and not all groups finished the entire practice task, we chose the ratio of deep SSR behaviour rather than the frequency as one evaluation variable and task completion scores as another.

For comparing the temporal flow of SSR behaviours across different clusters, Disco (https://www.fuxicon.com/disco/) was used, a process mining software with the fuzzy algorithm, which is a common algorithm to explore the regulation process [4, 20]. To make the visualization more comprehensible, we filtered the data to keep the percentage of paths at a minimum (0%), showing the strongest sequential associations between different categories.

4. Results and Discussion

Each dyad's recording data consisted of at least 50 minutes of discussion. The speech recordings data comprised 5,761 SSR behaviours. These categories included 317 (5.5%) behaviours for Orientation, 755 (13.1%) for Planning, 271(4.7%) for Support strategies, 3899 (67.7%) for Monitoring, and 519 (9%) for Evaluation and reflection.

4.1 RQ1

K-means cluster analysis was performed to cluster the SSR group profiles based on the speech measures of collaborative groups' adoption ratio of deep levels' SSR behaviours and task completion scores. Based on the distribution of corresponding standard scores, a three-clusters solution (k=3) is suitable (see Figure 1 left), and three clusters were produced (see Figure 1 right). Considering the features of the ratio of deep levels SSR behaviours and task completion score, we labelled these three clusters as "high deep-SSR-behaviours-ratio high task-completion" ("HdeepHtask"), "low deep-SSR-behaviours-ratio high task-completion" ("LdeepHtask"), and "high deep-SSR-behaviours-ratio low task-completion" ("HdeepLtask"), respectively. Unlike previous studies that the frequency of the deep-level SSR behaviours related to high group performance [3], it is not the case in this study. From the task completion perspective, a high ratio of deep level SSR behaviour could produce both high and low task completion, while a low ratio of deep level SSR behaviour could lead to high task completion (based on the three clusters found in this study). The reason might lie in the task difference. The task used in this study is a highly synchronous collaborative operation task where the monitoring phase was the most frequently observed regulation phase. This aligns with the results from [23] using educational research design as task where the monitoring phase had the highest mean proportion, unlike the results from [4] using physic poster design as a task where planning was the most frequently observed regulation phase.

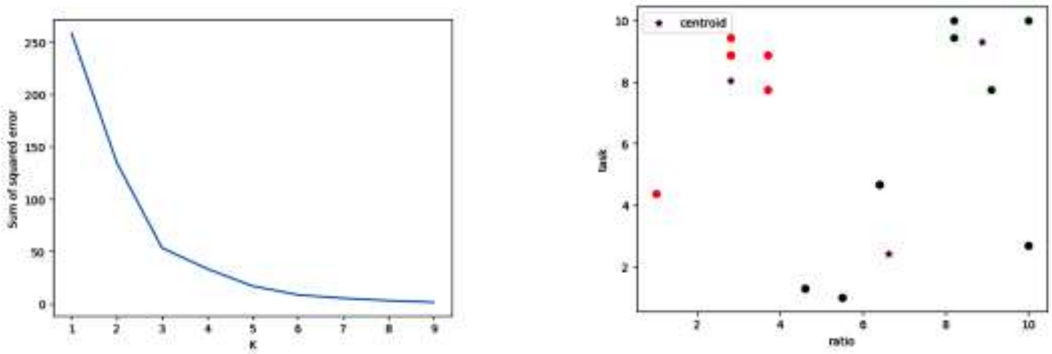

Figure 1. K-means clustering results (left: optimal clusters of "k" with the elbow method; right: visualization of the k-means clustering results (k=3)).

4.2 RQ2

Considering we focused on the process differences, we only compared two cluster which shared similar task operation scores, "HdeepHtask" and "LdeepHtask" respectively.
To examine the sequence differences of the SSR in the CPS across SSR profiles, process mining was employed to analyse the group SSR behaviours in a temporal sequence. Regularities were detected in the transition patterns, and each cluster related to one SSR sequence features. To better understand the SSR behaviour patterns, we manually divided the process into five parts (the horizontal lines in the figures) after comparing these figures. Overall, "Monitoring of Progress", "Comprehension Monitoring", "Interim Planning" were frequent SSR behaviours in all three clusters (the dark blue box in Figure 2 and 3). In these figures, the darker the blue of the box, the higher of the frequency of the behaviour. (Clear figures available at: https://osf.io/pd8s7/?view_only=ab687610de7147f1bfaa6c917d449af4)
The SSR process for "HdeepHtask" cluster is illustrated in Figure 2. Groups in this cluster began with "Monitoring of Progress" and "Comprehension Monitory". Then, students in this cluster tended to deeply analyze the task, including "Planning in Advance" -> "Content Orientation", "Evaluating Learning Outcomes" -> "Task Analysis" or "Planning in Advance" -> "Task Analysis". After this, there was a main path, "Interim Planning" -> "Evaluating Learning Process" -> "Task Analysis". No Support strategies were found in this SSR profile. Based on the features of the regulation process, this cluster can be labelled as "Intragroup-elaborating-oriented regulation process group".
The SSR process for "LdeepHtask" cluster is illustrated in Figure 3. Like the "HdeepHtask" cluster, this cluster started with "Monitoring of Progress" and "Comprehension Monitory". Unlike the "HdeepHtask" cluster, this cluster followed "Planning in Advance" -> "Task Analysis" and then demonstrated different paths, namely, "Evaluating Learning outcomes", "Online Searching", or "Evaluating Learning Outcomes" -> "Interim Planning". After this, these three paths converged on the path "Content Orientation" -> "Peer Interaction". As a path loop, "Peer Interaction" stepped into "Task Analysis",

which appeared before. “Peer Interaction” and “Online Searching” as Support strategies were both found. Considering common behaviours were categorised across all five dimensions, this cluster can be labelled as “All-round-oriented regulation process group”.

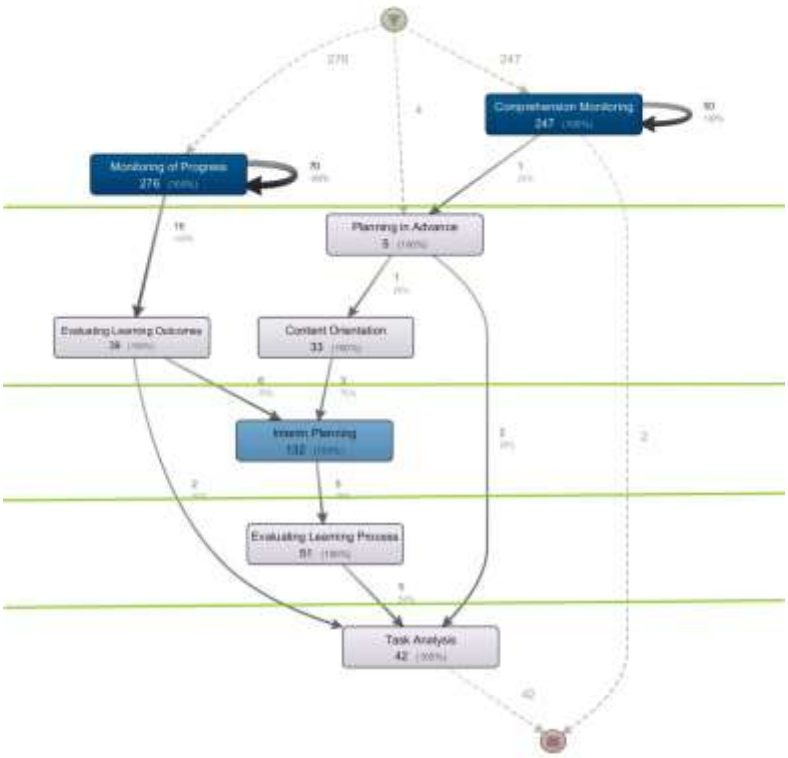

Figure 2. Sequential SSR behaviours in “HdeepHtask”.

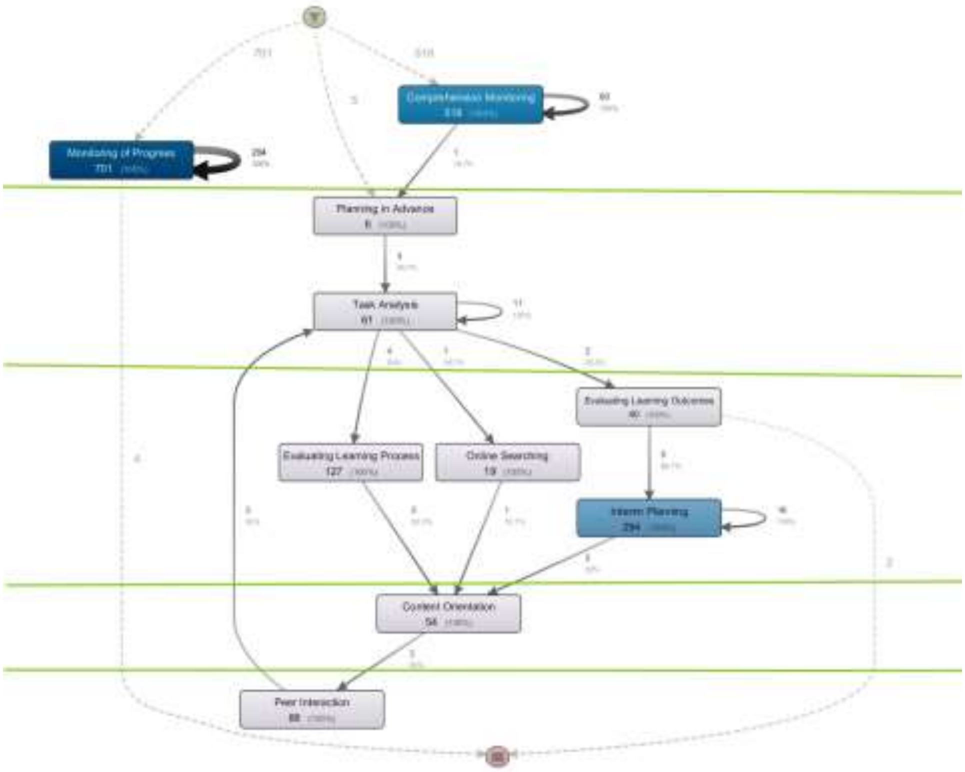

Figure 3. Sequential SSR behaviors in “LdeepHtask”.

Different from the sequential patterns in [4], where planning->task understanding was the beginning, our group regulation behaviours mostly started from Monitoring phase (Monitoring of Progress or Comprehension Monitoring). The difference might lie in the task types. The CPS in [4] involved creating posts about a physics topic, which need more discussion (38% behaviours in share/compare and 26% behaviours in negotiate/co-construct, as shown in their descriptive statistics for knowledge construction phases). Our tasks required students to identify the real situation in their own computer settings according to task requirements and then operate the ICMP packet sending and receiving step by step. Therefore, as a testing function, monitoring phase at the beginning helped students compare and match the task requirements and their computers' real settings and then forming operation plans.

5. Conclusion and Implications

This study explored how SSR emerged sequentially in formal face-to-face engineering operating courses. Encouraging discussion and providing guidance for task-oriented conversations are critical for successful CPS activities. Active participation in group learning activities can be limited to inefficient solution plaining without co-construction of knowledge based on the prior execution results. At this moment, multiple support strategies should be encouraged to help groups critically reflect on their execution process and propose iterated solutions. More importantly, guiding groups to realize the multiple functions of SSR would help them adjust execution rhythm within limited time [11].

This study also sheds light on the design of CSCL scripts in CPS to deal with authentic problems. CPS stimulates the inquiry process and covers related domain knowledge and operation procedure through the careful selection of authentic problems [13]. CSCL scripts potentially scaffold SSR behaviour in CPS by setting milestones to help with their current working plan, externalising scaffolding to reflect on the execution process, and evaluating group artefacts through shared efforts.

What's more, prompting and scaffoldings from instructors is necessary, especially in face-to-face CPS operating courses. It is not only about the technical help instructors provide but also about how to adjust the task demands according to real operation situations and the enhancement of social presence the success with authority. For instance, the speech recordings showed that some groups had to change their computers for the successful completion of the operation tasks but was unsure whether this solution was allowed. Some groups excitedly told the instructor about their success in subtasks when the instructor walked nearby. At the same time, instructors could raise or reduce the difficulty of the group tasks according to teaching experience, the limitations of course duration, and familiarity with individual learners.

Several limitations can be found in this study. Firstly, the sample size of this study was small, which limited the generalization of the findings. Second, we did not delve into the intergroup interactions in the face-to-face course due to the non-consecutive speech recordings of related behaviours and not all groups asked for peer help. Further steps to investigate the intergroup interactions could potentially provide insights into the group awareness.

REFERENCES

[1] Fiore S. M., Graesser A., Greif S., “Collaborative problem-solving education for the twenty-first-century workforce”, Nature Human Behaviour, 2018, 2(6), 367.

[2] Jeong H., Hmelo-Silver C. E., Jo K., “Ten years of computer-supported collaborative learning: A meta-analysis of CSCL in STEM education during 2005–2014”, Educational Research Review, 2019, 28, 100284.

[3] De Backer L., Van Keer H., Valcke M., “The functions of shared metacognitive regulation and their differential relation with collaborative learners' understanding of the learning content”, Learning and Instruction, 2022, 77, 101527.

[4] Zabolotna K., Malmberg J., Järvenoja H., “Examining the interplay of knowledge construction and group-level regulation in a computer-supported collaborative learning physics task”, Computers in Human Behavior, 2023, 138, 107494.

[5] Dillenbourg P., Fischer F., “Computer-supported collaborative learning: The basics”, Zeitschrift für Berufs-und Wirtschaftspädagogik, 2007, 21, 111–130.

[6] Radkowitsch A., Vogel F., Fischer F., “Good for learning, bad for motivation? A meta-analysis on the effects of computer-supported collaboration scripts”, International Journal of Computer-Supported Collaborative Learning, 2020, 15, 5–47.

[7] Cai H., Gu X., “Factors that influence the different levels of individuals’ understanding after collaborative problem solving: The effects of shared representational guidance and prior knowledge”, Interactive Learning Environments, 2022, 30(4), 695–706.
[8] Sharma K., Nguyen A., Hong Y., “Self - regulation and shared regulation in collaborative learning in adaptive digital learning environments: A systematic review of empirical studies”, British Journal of Educational Technology, 2024, 55(4), 1398-1436.
[9] Haataja E., Dindar M., Malmberg J., Järvelä S., “Individuals in a group: Metacognitive and regulatory predictors of learning achievement in collaborative learning”, Learning and Individual Differences, 2022, 96, 102146.
[10] Vuorenmaa E., Järvelä S., Dindar M., Järvenoja H., “Sequential patterns in social interaction states for regulation in collaborative learning”, Small Group Research, 2023, 54(4), 512-550.
[11] Iiskala T., Volet S., Lehtinen E., Vauras M., “Socially shared metacognitive regulation in asynchronous CSCL in science: Functions, evolution and participation”, Frontline Learning Research, 2015, 3(1), 78-111.
[12] Menekse M., Purzer S., Heo D., “An investigation of verbal episodes that relate to individual and team performance in engineering student teams”, International Journal of STEM Education, 2019, 6(1).
[13] Van Den Beemt A., Macleod M., Van Der Veen J., Van De Ven A., Baalen S., Klaassen R., Boon M., “Interdisciplinary engineering education: A review of vision, teaching, and support”, Journal of Engineering Education, 2020, 109(3), 508–555.
[14] Vogel F., Wecker C., Kollar I., Fischer F., “Socio-cognitive scaffolding with computer-supported collaboration scripts: A meta-analysis”, Educational Psychology Review, 2017, 29, 477-511.
[15] Miller M., Hadwin A., “Scripting and awareness tools for regulating collaborative learning: Changing the landscape of support in CSCL”, Computers in Human Behavior, 2015, 52, 573–588.
[16] Näykki P., Isohätälä J., Järvelä S., Pöysä-Tarhonen J., Häkkinen P., “Facilitating socio-cognitive and socio-emotional monitoring in collaborative learning with a regulation macro script–an exploratory study”, International Journal of Computer-Supported Collaborative Learning, 2017, 12, 251-279.
[17] Jacobson M. J., Levin J. A., Kapur M., “Education as a complex system: Conceptual and methodological implications”, Educational Researcher, 2019, 48(2), 112–119.
[18] Iiskala T., Volet S., Jones C., Koretsky M., Vauras M., “Significance of forms and foci of metacognitive regulation in collaborative science learning of less and more successful outcome groups in diverse contexts”, Instructional Science, 2021, 49(5), 687-718.
[19] De Backer L., Van Keer H., Valcke M., “Variations in socially shared metacognitive regulation and their relation with university students’ performance”, Metacognition and Learning, 2020, 15(2), 233-259.
[20] Vuorenmaa E., Järvelä S., Dindar M., Järvenoja H., “Sequential patterns in social interaction states for regulation in collaborative learning”, Small Group Research, 2023, 54(4), 512-550.
[21] Lyu Q., Chen W., Su J., Heng K. H., “Collaborate like expert designers: An exploratory study of the role of individual preparation activity on students' collaborative learning”, The Internet and Higher Education, 2023, 59, 100920.
[22] De Backer L., Van Keer H., Moerkerke B., Valcke M., “Examining evolutions in the adoption of metacognitive regulation in reciprocal peer tutoring groups”, Metacognition and Learning, 2016, 11, 187-213.
[23] Ader M., Hassane S., van Bruggen J., Vermeulen M., “Comparing metacognitive regulation and socially shared metacognitive regulation in face-to-face and online learning settings in ill-structured problem solving”, Learning, Culture and Social Interaction, 2023, 39, 100684.