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Interplay of metacognitive experiences and performance in collaborative problem solving

Abstract

Metacognitive experiences are the feelings and judgments that emerge in relation to an ongoing learning task. Much of the work on metacognitive experiences has studied these constructs piecemeal and mostly in individual learning settings. Thus, little is known about how metacognitive experiences co-occur in social learning settings. In light of this, we investigated the relationships between metacognitive experiences and their impact on perceived and objective task performance in a collaborative problem solving (CPS) simulation. Seventy-seven higher education students participated in the study. Metacognitive experiences (judgment of confidence, mental effort, task difficulty, task interest, and emotional valence) were measured with self-reports at multiple time points during CPS. A path analysis was conducted to investigate the relationship between metacognitive experiences and perceived performance. A generalized estimating equation was used to observe the relationships between metacognitive experiences and objective group CPS performance. Overall, the findings indicate complex relationships among the metacognitive experiences and performance in CPS and further highlight the social characteristics of metacognition.

Keywords: Collaborative problem solving; metacognitive experiences; socially shared metacognition; complex problem solving.

1. Introduction

The current complex global and local challenges require people to solve problems together (He, von Davier, Greiff, Steinhauer, & Borysewicz, 2017). Thus, there has been a growing emphasis on improving collaborative problem solving (CPS) of 21st century individuals (Care, Scoular, & Griffin, 2016). CPS is a joint activity in which multiple individuals combine their resources, skills, and efforts to transform a problem state to a desired state (OECD, 2013). The two key dimensions of CPS have been defined as cognitive and social (Andrews-Todd & Forsyth, 2018; Hesse, Care, Buder, Sassenberg, & Griffin, 2015). In the cognitive dimension, group members work together to develop a shared understanding of the problem situation, exchange information, discuss the most appropriate strategies to solve the problem, and monitor and revise their strategies until the group goals are attained (Barron, 2003; Slof, Erkens, Kirschner, Jaspers, & Janssen, 2010; Zimmerman & Schunk, 2011). The social dimension includes communicative processes among the team members that can either facilitate or hinder the collaborative processes in the cognitive dimension (Janssen, Erkens, Kirschner, & Kanselaar, 2012). Participation, perspective taking, argumentation, negotiation, and emotional and motivational interaction are examples of such communicative processes (Hesse et al., 2015; Slof, Erkens, Kirschner, Janssen, & Phielix, 2010). Research has shown that successful collaboration is not easy to achieve and requires the effective coordination of individual and group processes in both the cognitive and social dimensions (Baker, Greenberg, & Gutwin, 2001; Barron, 2003; Author, 20XX). In this regard, CPS involves high levels of metacognition to oversee of such processes (Dierdorff & Ellington, 2012; Flavell, 1979).

Metacognition is defined as one's own knowledge about cognition and regulation of cognitive processes toward specific goals (Brown, 1987). Historically, metacognition has been conceptualized as an endogenous phenomenon that occurs in an individual's mind (Dinsmore, Alexander, & Loughin, 2008). Thus, the primary emphasis in metacognition research has thus far been on individualistic learning (Iiskala, 2015). According to the socio-cognitive view, learning is both a social and a cognitive process in which knowledge is negotiated and co-constructed by multiple individuals (Resnick, 1991; Schoor, Narciss, & Körndle, 2015). In this regard, metacognition should be viewed as a social rather than solely an individual phenomenon

(Goos, Galbraith, & Renshaw, 2002). Although early metacognition research has mentioned social interaction and social context as facilitators of metacognition (Brown, 1978; Flavell, 1979), only in the last decade has more research on the influence of social interaction on metacognition gradually emerged (McCarthy & Garavan, 2008).

Overall, studies that have investigated metacognition in social learning settings have mostly focused on its cognitive aspects, such as task content processing (Volet, Vauras, Salo, & Khosa, 2017), content knowledge discussion (Hmelo-Silver & Barrows, 2008), monitoring and regulation of content processing (Author 20XX; Iiskala, Vauras, Lehtinen, & Salonen 2011; Nonose, Kanno, & Furuta, 2014), and judgment of confidence in content/task processing (Dierdorff & Ellington, 2012; Hadwin & Webster, 2013). However, it is known that subjective feelings (e.g., motivation and emotions) form the basis for the metacognition (Koriat & Levy-sadot, 2000). There is a growing body of research focusing on the regulation of motivation and emotions in social learning settings, which includes the metacognitive dimension that is present through regulatory processes (Hadwin, Järvelä, & Miller, 2011). Lajoie et al. (2015), for example, investigated how metacognition, coregulation, and social emotional activities occurred between collaborative medical students in the context of an international web-problem-based learning environment. Bakhtiar, Hadwin, & Webster (2018) investigated emotion regulation and socioemotional interactions in a positive and a negative group climate. In their model, metacognition knowledge, beliefs, and processes are considered to fuel the group-level regulation. Nonetheless, little attention has been paid to the motivational and emotional aspects of metacognition (Efklides, 2006). Consequently, there is limited understanding on how the cognitive, motivational, and emotional aspects of metacognition in CPS might be associated. Such knowledge would enable the design of better support for learners to help them tackle the cognitive, affective, and social challenges that emerge during CPS (Nussbaum et al., 2009).

To address this gap, our study focuses on a particular aspect of metacognition, namely, metacognitive experiences in CPS. Metacognitive experiences are subjective judgments and feelings about an ongoing learning task and its outcomes (Efklides, 2002a). Metacognitive experiences provide cognitive and affective cues to metacognition that are necessary for taking relevant actions to progress with the task (Efklides, 2011). Considering the importance of metacognitive experiences for metacognition, our study investigates the *interplay of several metacognitive experiences* during CPS and CPS performance. We argue that metacognitive experiences are intervening processes contributing to CPS performance.

There is a growing body of work on group members' perceptions about various CPS processes. These perceptions include students' attitudes about collaboration (Dobao & Blum, 2013), group-level affective states (Barsade & Gibson, 2012), teamwork satisfaction (Ku, Tseng, & Akarasriworn, 2013), ratings of group performance, and the communication, cooperation and agreeableness among the collaborating students (Stewart & D'Mello, 2018). Extending such work from a task-oriented perceptions perspective, our study focuses on students' thoughts and feelings regarding the monitoring and control of CPS task progress. Humans' perceptions about a learning/problem solving task is a product of their metacognition which is central in fueling thinking and cognition. Therefore, we based our study on metacognition theory and we chose our measurement instruments from metacognition research.

This study makes several contributions. First, a growing body of research has acknowledged the social nature of metacognition (Author, 20XX; Efklides, 2008; Iiskala et al., 2004). Studies that investigated social characteristics of metacognition have so far dealt with capturing shared metacognitive monitoring or shared metacognitive control instances in CPS (Author, 20XX; Iiskala et al. 2011). The current study differs from the pertinent literature by focusing on the subjective metacognitive feelings and judgments that emerge in relation to metacognitive monitoring. This is because metacognitive monitoring is a mental process. Thus, it is challenging to capture metacognitive monitoring instances during collaboration unless the learners verbally explicate their metacognitive monitoring (Author, 20XX). However, metacognitive experiences, manifestations of metacognitive monitoring, can be easily captured with available self-reported measures in the literature. Thus, we hypothesize that studying metacognitive experiences can serve as a proxy to understand the quality of metacognitive monitoring in CPS. Further, our study presents a holistic view on the associations between various metacognitive experiences in CPS. To our knowledge, this is the first study to explore the interrelatedness of multiple metacognitive experiences in CPS.

Second, metacognitive experiences are considered situated and temporal (Efklides, 2009). Thus, a snapshot approach that only studies them prospectively or retrospectively in a CPS activity may provide a limited understanding of the complex and dynamic nature of the CPS process (Reiter-Palmon, Sinha, Gevers, Odobez, & Volpe, 2017). With the exception of a few studies (Ainley, Hidi, & Berndorff, 2002; Efklides, 2002a; Tapola, Veermans, & Niemivirta, 2013), metacognitive experiences have not been measured during tasks. Rather, they have been measured before or after the task. Given this, we measured these experiences with situated self-reports before, during, and after CPS. This is in line with a growing body of research that has been adopting methods to capture collaborative learning processes at multiple time points (Author, 20XX). Such research contributes to a more fine-grained understanding of CPS activities.

Third, the use of computer-based environments is widespread in measuring CPS, such as in worldwide PISA exams (Graesser et al., 2018). It is important to understand how specific design features impact social interactions and performance in computer-based CPS. However, there is little empirical research on how specific design features in such environments affect CPS processes and outcomes (Herborn, Stadler, Mustafić, & Greiff, 2018). The current study responds to this issue by investigating metacognitive experiences and performance in a computer-based CPS. In the simulation, team members were provided continuous feedback about their goal attainment. Thus, the study yields practical implications about embedding feedback features in computer-based CPS simulations.

2. Literature review

2.1. Metacognitive monitoring and metacognitive experiences

Metacognition includes two basic functions: monitoring and control (Dunlosky & Metcalfe, 2009). Metacognitive monitoring helps learners to detect internal (mental) and external (contextual) discrepancies in terms of reaching the goals or standards they have set (Winne, 2019). Metacognitive monitoring informs individuals about how to adapt a behavior in order to respond to the environment and develop learning and performance further (de Bruin & Van Gog, 2012). Metacognitive control guides the regulatory processes during learning based on the information provided by the metacognitive monitoring (Baker & Brown, 1984; Nelson & Narens, 1990). Metacognitive control processes include planning, time and effort allocation to the task, regulation of task processing, and evaluation of the task outcome (de Bruin & Dunlosky, 2017). The accuracy of metacognitive monitoring is crucial in terms of activating relevant metacognitive control processes for successful regulation of a learning task (Koriat, Ma'ayan, & Nussinson, 2006).

It has been claimed that regulatory processes are activated by one aspect of metacognitive monitoring: *metacognitive experiences* (Efklides, 2011), which are the concurrent feelings and judgments about the process and outcome of an ongoing task (Efklides, Kourkoulou, Mitsiou, & Ziliaskopoulou, 2006).They serve as the interface between the learner and the task. Metacognitive experiences include cognitive, emotional, and motivational cues that inform about the quality of task progress (Efklides, 2001). Thus, they have a crucial role in facilitating metacognitive control processes for short- and long-term self-regulation.

The prominent metacognitive experiences that emerge during an ongoing task are the judgment of confidence, task interest, estimates of mental effort, feeling of difficulty, and emotions (Efklides, 2002b, 2005). "Judgment of confidence" is a metacognitive self-evaluation that informs on the difference between one's actual performance and the self-standard set for the performance (Hadwin & Webster, 2013). It activates regulatory processes during an ongoing task if the standards are not met (Boekaerts & Rozendaal, 2010). "Task interest" has been defined as the extent to which one finds performing a task important, valuable, and enjoyable (Cleary & Chen, 2009). It is a self-motivational belief that predicts the activation of regulatory strategies when learners encounter challenges during learning (Schunk & Ertmer, 2000).

“Estimates of mental effort” comprises judgments about the degree of mental effort to be allocated to the task (Efklides, 2002a, 2006). “Feeling of difficulty” refers to the subjective experiences that emerge due to the objective task difficulty, prior performance, and self-efficacy (Bandura, 1997; Mangos & Steele-Johnson, 2004). It arises when the learner lacks an awareness of the immediate responses to the challenges in the task at hand (Efklides, Papadaki, Papantoniou, & Kiosseoglou, 1998a). It has been also asserted that emotions are an essential part of metacognitive experiences and signal the pleasantness or unpleasantness of an online task (Efklides, 2001, 2006).

Metacognitive experiences have been mainly seen as feelings and judgements related to one’s self-regulation (Efklides, 2006). Thus, previous studies have mostly examined metacognitive experiences mostly in individual learning settings with math problem solving tasks. In terms of feeling of difficulty, some studies reported no relationship between feeling of difficulty and affective states, such as mood, fear of failure, and need for success (Efklides et al., 2006, 1998). However, other studies reported significant relationships between feeling of difficulty, negative mood (Efklides & Petkaki, 2005), and emotions (Tornare, Czajkowski, & Pons, 2015). No direct relationship was found between feeling of difficulty and judgment of confidence (Efklides, 2002b). In terms of task interest, a positive relationship was found between positive mood and task interest (Efklides & Petkaki, 2005). In terms of estimates of effort, studies reported both positive (Efklides & Petkaki, 2005) and negative (Efklides & Petkaki, 2005) relationships and no relationship (Efklides et al., 2006) between positive mood and estimates of effort depending on the measurement time (i.e., before or after the task). Significant relationships were observed between judgment of confidence, emotions, and positive mood (Efklides & Petkaki, 2005; Nerantzaki & Efklides, 2019).

Concerning the relationship between metacognitive experiences and performance in individual math problem solving, several studies have reported a positive relationship between combined metacognitive experiences (i.e., feeling of difficulty, feeling of familiarity, estimate of correctness, estimate of effort, and judgment of understanding), scores, and performance (Aşık & Erktin, 2019; Özcan & Eren Gümüş, 2019). A significant relationship was also reported between performance and specific metacognitive experiences, such as feeling of difficulty, judgment of confidence (Efklides, 2002b), estimates of effort (Efklides et al., 2006), and emotions (Tornare et al., 2015). However, some studies reported no relationship between performance and several metacognitive experiences, such as feeling of difficulty (Efklides, 2002b) or affective states (e.g., mood; Efklides & Petkaki, 2005). It should be noted that studies mostly treated performance measures as the independent variable predicting metacognitive experiences (Efklides, 2002b; Efklides et al., 2006, 1998; Tornare et al., 2015). However, some regarded performance as the dependent variable predicted by the metacognitive experiences (Asik & Erktin, 2019; Ozcan & Gumus, 2019). Therefore, the current literature on the relationship between metacognitive experiences and performance might not be comparable.

Metacognitive experiences can be also disseminated among the collaborating individuals through verbal or facial expressions (Efklides, 2006). For example, exchanging metacognitive experiences among the group members can contribute to the shared metacognitive monitoring and provide valuable information about shared cognition and task progress (Efklides, 2008). So far only few empirical studies have investigated metacognitive experiences in collaborative settings, mostly through video coding of student interactions in math problem solving (Iiskala et al., 2004, 2011; Salonen et al., 2005). Such studies have found that metacognitive experiences could facilitate shared regulatory processes during CPS (Iiskala et al., 2004, 2011). Findings further showed that misperceptions about others’ metacognitive experiences can have detrimetal effects on collaboration quality (Salonen et al. 2005). In the literature, only one study was identified that investigated metacognitive experiences in a collaborative setting outside of math problem solving (Hamilton, Mancuso, Mohammed, Tesler, & McNeese, 2017). In the study, teams of three members were given a simulation about emergency management in a fictional city. The regression results showed no relationship between judgment of task confidence and objective group performance.

Overall, studies on metacognitive experiences are limited to individual math problem solving. Therefore, their findings might not be applicable to CPS settings in which task performance is dependent on the interactions among the learners in addition to their individual characteristics, skills, or prior knowledge.

Further, the literature presents contradictory findings about the relationships among metacognitive experiences and performance, although it does provide evidence that metacognitive experiences emerge in CPS and influence the quality of collaboration. Nevertheless, the limited amount of research on the issue makes it difficult to infer the connections between specific metacognitive experiences and the mechanism that connects them to performance outcomes (Efklides, 2011). Little is yet known about the relationships between various metacognitive experiences and their influence on CPS performance. In light of this, we explored the interplay of metacognitive experiences during CPS and their relationship with group and individual performance.

2.2. Conceptual model and hypothesis development

The aim of this study is to investigate the interplay of metacognitive experiences during CPS and their influence on performance. Considering metacognitive experiences in CPS context, we build our hypotheses on the studies related to metacognition and metacognitive experiences in various research fields (e.g., cognitive load, motivation, and emotions research), since it broadens the current perspectives relevant to CPS context.

Effective regulation of cognition, motivation, and emotions, which are mediated by metacognitive experiences, should lead to better learning outcomes and/or task performance (Efklides, Schwartz, & Brown, 2018; Hadwin et al., 2017). To test this assumption, we included two perceived performance outcomes in the conceptual model: perceived group performance and perceived individual performance. In highly complex collaborative tasks that require high interdependence, group members need to interact intensely and work together to accomplish the task goals (Stajkovic, Lee, & Nyberg, 2009). In such tasks, an individual's functioning and performance is highly dependent on the group's functioning as a whole (Lindsley, Brass, & Thomas, 1995). Therefore, we hypothesize the following:

H1: Perceived individual performance is related to perceived group performance in CPS.

Learners rely on their metacognitive judgments to regulate their performance (Blisset et al., 2018). Inaccurate judgments about a task's progress may have detrimental effects on regulation of efforts and task outcomes (Cavalcanti & Sibbald, 2014). For example, overconfidence about performance in a challenging task can lead to investing less effort, which may be insufficient to accomplish the desired goal (Ackerman & Goldsmith, 2011). However, if learners are provided with metacognitive monitoring cues (e.g., feedback) on their task progress, the discrepancy between their metacognitive judgments and their task performance diminishes (de Bruin, Dunlosky, & Cavalcanti, 2017). Participants in this study received feedback about their task progress at specific time points during CPS. Thus, we assume the following:

H2: Judgments of confidence about group goal attainment are related to the perceived group performance.

Motivational self-beliefs affect the utilization of self-regulatory processes (Eccles & Wigfield, 2002). Specifically, task interest has been found to predict students' self-regulation and achievement (Ainley et al., 2002; Eccles, 2009). Considering the influence of task interest in sustaining task engagement, especially when challenges are encountered during the task (Schunk & Ertmer, 2000), it can be expected that learners with high task interest would have greater achievement.

H3: Task interest is related to perceived individual performance.

Groups' collective success in CPS depends on their members' metacognitive and motivational efforts in sustaining group attachment to the joint work until the task is accomplished (Author, 20XX; Bergin, 2016). Interest, in turn, unifies motivation with affective and cognitive components (Hidi, 2006). Accordingly, motivated attachment to CPS can be maintained through situational task interest, which is supported by social involvement (Dohn, 2013; Renninger & Bachrach, 2015). According to this view, for groups in which social involvement support individual's task interest, group members would put more effort into the work, which eventually improves the group performance. Therefore, we hypothesize the following:

H4: Task interest is related to perceived group performance.

Studies in individual learning settings have mostly found a negative relationship between task interest and task difficulty (Clark, 1999; Fulmer & Tulis, 2013; Kumar & Jagacinski, 2011), showing that if a task appears to be too difficult, students' willingness to pursue decreases. However, it is also known that interest is triggered if the task includes challenges and demands (Chen, Darst, & Pangrazi, 1999; Csikszentmihalyi, 1975). In addition, a basic assumption of collaborative learning is that learners are interested in collaboration if they cannot reach the task goals without the contributions of others (Johnson, Maruyama, Johnson, Nelson, & Skon, 1981). In line with this assumption, several studies have shown that difficult tasks lead to increased interaction and shared metacognition in collaborative learning (Iiskala et al., 2004, 2011). Given this, a positive rather than negative relationship can be assumed between task interest and task difficulty in CPS.

H5: Task difficulty is related to task interest.

The empirical evidence has shown that emotional valence (i.e., positive or negative emotions) and task interest are intertwined and together play a causal role in persistence in task (Ainley, Corrigan, & Richardson, 2005; Ainley et al., 2002; Efklides, 2001, 2011). Thus, we hypothesize the following:

H6: Emotional valence is related to task interest.

Subjective feelings provide an informational basis for judgments and behavior (Koriat & Levy-sadot, 2000; Schwarz & Clore, 1996). Thus, emotional valence is regarded as an important component of metacognitive judgments (Efklides, 2006). For example, Hadwin and Webster (2013) found that positive emotions positively predicted judgments of confidence about goal attainment. Similarly, several studies have reported a significant relationship between emotions and self-efficacy beliefs (Pekrun et al., 2004; Putwain, Sander, & Larkin, 2013). Given this, we hypothesize the following:

H7: Emotional valence is related to judgment of confidence in group goal attainment.

Mental effort has been found to relate to self-efficacy and metacognitive judgments (Feldon, Callan, Juth, & Jeong, 2019; Koriat, Nussinson, & Ackerman, 2014). Some scholars have asserted that mental effort can be a cue that guides metacognitive judgments (Blissett, Sibbald, Kok, & van Merrienboer, 2018). Considering such findings, the following can be assumed:

H8: Mental effort is related to judgment of confidence in goal attainment.

According to theories of motivation, a prominent indicator of motivation is the mental effort exerted on a task (Hadwin et al., 2017; Pintrich & De Groot, 1990; Wigfield & Eccles, 2000). Studies have shown that motivated individuals invest more mental effort on learning tasks (Rey & Buchwald, 2011). Such studies have mostly regarded motivation as a precursor to that mental effort. However, some recent studies have found that mental effort can also directly influence motivational beliefs (Feldon, Franco, Chao, Peugh, & Maahs-Fladung, 2018; Likourezos & Kalyuga, 2017). On this basis, we hypothesize the following:

H9: Mental effort is related to task interest.

Figure 1 displays the conceptual model and the hypotheses.

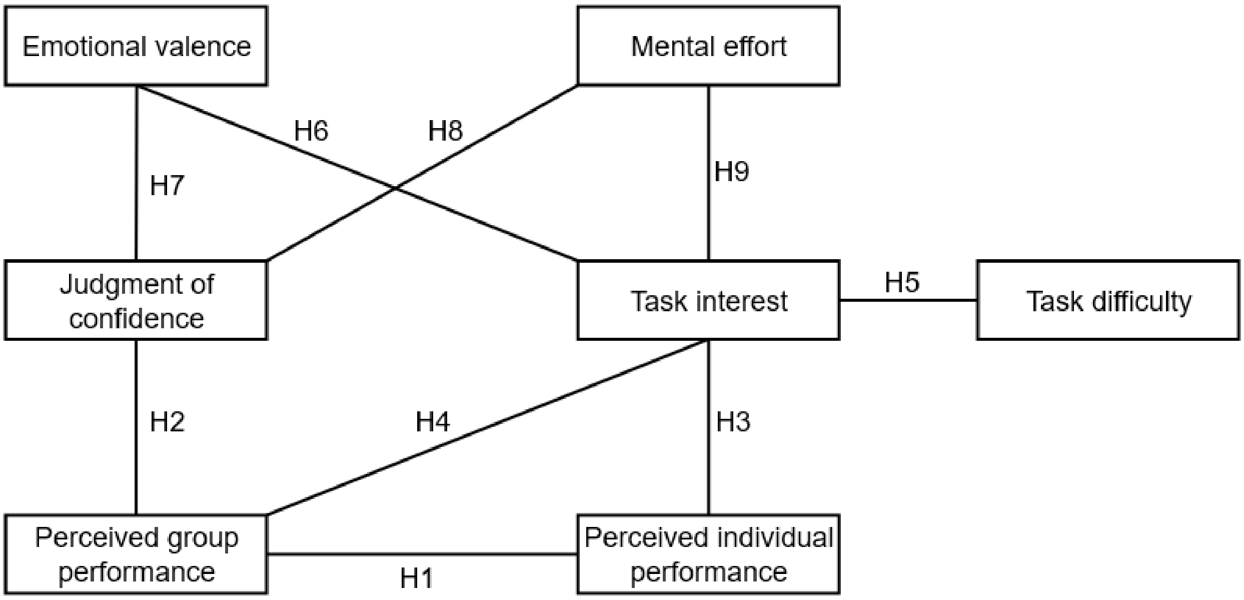

Fig.1. Conceptual model. The lines indicate hypothesized relationships.

The variables identified in Figure 1 were measured at the individual level in this study. In addition, the study includes an objective CPS performance score measured at the group level. Although it was not possible to include the group-level CPS score in the path analysis, it was worth investigating how the collective metacognitive experiences of a group affects the objective CPS performance. Thus, the current study also explores the relationship between group-level collective metacognitive experiences and objective group CPS performance.

3. Methodology

3.1. Participants

The participants were 77 higher education students ($n_{females}$= 41; n_{males}= 33; M_{age} = 27.8; SD_{Age}= 5.43) from international degree programs ($f_{Master's}$ = 52; f_{PhD} = 16; $f_{Bachelor's}$ = 5) at the University of Oulu, Finland. The participant profile included 35 different nationalities, of which Chinese (*n* = 12), Finnish (*n* = 7), Pakistani (*n* = 5), Vietnamese (*n* = 4), Mexican (*n* = 3), and Polish (*n* = 3) were the most common. Participants took part in the CPS task in groups of three (*n* = 25) or two (*n* = 1). Three students from different groups withdrew, and their data were excluded from the dataset. Thus, the final dataset included 74 participants who collaborated in groups of three (*n* = 22) or two (*n* = 4).

3.2. The CPS task

The Tailorshop computer-based simulation was used. It was originally developed by Dörner, Kreuzig, Reither, and Stäudel (1983) and has been in use for decades to measure individuals' complex problem-solving skills (Barth & Funke, 2010; Danner, Hagemann, Schankin, Hager, & Funke, 2011). In Tailorshop, participants run a fictional shirt production company for 12 simulated months. In total, Tailorshop includes 24 variables, 12 of which the participants can directly manipulate. The remaining variables can only be manipulated indirectly, through changes in the variables that can be directly manipulated. The objective in Tailorshop is to increase the company's value to the highest possible value. The company's value depends on the complex relationship between the variables in the simulation. In each simulated month, participants as a group make decisions about how to manipulate the variables and input their decisions into the simulation.

When the group proceeds to the next month, the simulation updates the company value on the screen based on the group's input. Thus, the group receives feedback about the effectiveness of their decisions after each month. Tailorshop is completed in two phases: *exploration* and *performance*. In the exploration phase, participants become familiar with the simulation and develop prior knowledge about the relationships between the variables by running the simulation for six simulated months. Tailorshop does not keep a record of group performance during this phase. In the performance phase, the simulation starts from the beginning and records all inputs, including the company's value for each month.

3.3. Procedure

Recruitment was carried out through announcements on social media platforms and leaflets distributed on the university's premises. The volunteering participants registered for the data collection by completing an online form. Participation was voluntary, and the participants were able to withdraw at any time. A free lunch ticket was offered for participation.

Data collection took place in the Leaf research environment (https://www.oulu.fi/leaf-eng/) at the University of Oulu. Leaf is a classroom-like research infrastructure specifically designed for collecting data from collaborative learning activities. Leaf was separated into three distinct classrooms with portable, soundproofed walls to enable data collection from three groups concurrently. Participants provided information about their availability in the online registration form. Due to their limited availability, it was not possible to assign all of them to the collaborative groups randomly. Rather, those participants who were available at a specific date were randomly assigned to their groups. When participants arrived, they completed the consent forms and were introduced to their team members. Then, a researcher took each group to a separate room, seated the group before a desktop computer, and read them the instructions for completing the CPS task as a group. Using a prewritten text ensured that all groups received the same instructions. Situated self-reports were given to the group members in separate folders, each with five sets of reports. Participants were instructed to complete one set individually whenever the Tailorshop simulation prompted them to do so. After reading the instructions, the researcher left the room, and the group started the CPS simulation on the computer and completed the CPS task through face-to-face interactions in front of the computer. The Tailorshop simulation prompted participants to complete the situated self-report sets at specific times: at the beginning of the performance phase (after the exploration) and after months 3, 6, 9, and 12 during the performance phase. Table 1 displays the situated self-reports from each time point. The average CPS duration for the groups was calculated as 96 minutes (SD: 28.08).

Table 1
Time points at which participants completed situated self-reports in the Tailorshop simulation.

	Start	Month 3	Month 6	Month 9	Month 12
Judgment of confidence	✓	✓	✓	✓	✓
Mental effort	✓	✓	✓	✓	✓
Task interest	✓	✓	✓	✓	✓
Task difficulty	✓	✓	✓	✓	✓
Emotional valence	✓	✓	✓	✓	✓
Perceived individual performance					✓
Perceived group performance					✓

3.4. Measures

The current study aimed to capture metacognitive experiences repeatedly and with minimal interference to group interaction during CPS. Therefore, single-item self-report questionnaires that were already established in the literature were utilized to measure metacognitive experiences.

3.4.1. Mental effort

The single-item mental effort rating scale developed by Paas (1992) was used to measure mental effort invested by the participants during CPS. In the scale, participants were asked to rate the mental effort they had invested in the CPS task from 1 (*very, very low mental effort*) to 9 (*very, very high mental effort*).

3.4.2. Judgment of confidence

Judgment of confidence in attaining the task goal was measured with a single-item questionnaire developed by Hadwin and Webster (2013). Originally, the questionnaire was developed to measure confidence in individual goal attainment. For the current study purpose, the questionnaire was modified to ask "How confident are you that your team is attaining the current task goal?" Participants responded to the questionnaire by choosing a value between 1 (*I am not confident at all*) and 5 (*I am very confident*).

3.4.3. Task interest

Situational task interest during CPS was measured with a single-item questionnaire developed by Tapola et al. (2013) in which participants rated their task interest from 1 (*not interesting at all*) to 10 (*very interesting*).

3.4.4. Task difficulty

Based on Efklides, Papadaki, Papantoniou, and Kiosseoglou (1998b), participants were asked to rate the task's difficulty (i.e., "*This task seems to be…*") from 1 (*not difficult at all*) to 10 (*very difficult*) in a single-item questionnaire.

3.4.5. Emotional valence

Drawing on the circumplex model of emotions Pekrun, Frenzel, Goetz, and Perry (2007), the single-item emotional valence questionnaire asked participants to rate the pleasantness/unpleasantness of their current emotions (i.e., "How do you feel now?"). Participants answered on a scale ranging from 1 (*very, very negative*) to 9 (*very, very positive*). Similar versions of the questionnaire have been used in various studies (Ainley et al., 2005, 2002).

3.4.6. Perceived individual and group performance

Two separate single-item questionnaires were used to measure perceived group performance ("How was your group's performance during the task?") and perceived individual performance ("How was your individual performance during the task?"). Answers to the perceived group performance questionnaire ranged from 1 (*we performed very poorly*) to 10 (*we performed very well*). Similarly, responses to the perceived individual performance ranged from 1 (*I performed very poorly*) to 10 (*I performed very well*).

3.5.7. Tailorshop objective group performance

The reliable estimate of group CPS performance in Tailorshop has been determined to be the trend score (Danner et al., 2011), which is the total number of months that the group managed to increase the company value compared to the previous month. The score varies between 0 and 12. The current study utilized the trend score as the indicator of objective group performance.

4. Results

4.1. The relationship between metacognitive experiences and perceived performance

A path analysis was conducted to investigate the hypothesized relationships in the conceptual model (see Figure 1). For this aim, first, the stability of measures over time was checked with a reliability analysis. According to Cronbach's alpha (α) scores, reported metacognitive experiences scores were consistent over time ($\alpha_{\text{mental effort}} = .92$; $\alpha_{\text{task interest}} = .96$; $\alpha_{\text{task difficulty}} = .91$; $\alpha_{\text{judgment of confidence}} = .90$; $\alpha_{\text{emotional valence}} = .92$). The average scores for the repeated measures of judgment of confidence, mental effort, task interest, task difficulty, and emotional valence were calculated. Prior to the path analysis, the Pearson's correlations among the self-reported metacognitive experiences, emotional valence, and perceived performance scores were calculated. Table 2 displays the results.

Table 2
Bivariate individual-level correlations among the metacognitive experiences and perceived performance.

	2	3	4	5	6	7
Perceived group performance (1)	.752**	.556**	.459**	.339**	-0.038	.475**
Perceived individual performance (2)		.649**	.536**	.602**	0.102	.598**
Judgment of confidence (3)			.524**	.561**	-0.007	.729**
Mental effort (4)				.695**	.476**	.480**
Task interest (5)					.436**	.664**
Task difficulty (6)						0.002
Emotional valence (7)						

** Correlation is significant at the 0.01 level (two-tailed).

As can be seen in Table 2, there was a strong and positive correlation between perceived group and individual performance. Both types of performance were positively correlated with judgment of confidence, mental effort, task interest, and emotional valence at the medium level. No correlation was observed between task difficulty and perceived group or individual performance. Judgment of confidence was moderately related to mental effort and task interest. In addition, a high and positive correlation was observed between judgments of confidence and emotional valence. No correlation was observed between judgment of confidence and task difficulty. Mental effort was strongly correlated with task interest and moderately correlated with task difficulty and emotional valence. Task interest was positively and moderately correlated with task difficulty and emotional valence. No significant correlation was observed between task difficulty and emotional valence.

Table 2 indicated high correlations among some of the variables. Thus, multicollinearity among the variables were checked with the variance inflator factor (VIF) and tolerance indices prior to further analyses (Tabachnick & Fidell, 2007). It has been suggested that VIF values above 4 and tolerance values below 0.2 can be considered indicators of lack of multicollinearity (Hair, Black, Babin, & Anderson, 2009). In the current dataset, VIF and tolerance values for judgment of confidence (VIF = 2.62; tolerance = 0.38), mental effort (VIF = 2.63; tolerance = 0.38), task interest (VIF = 3.21; tolerance = 0.31), task difficulty (VIF = 1.80; tolerance = 0.56) emotional valence (VIF = 2.99; tolerance = 0.34), and perceived group performance (VIF = 1.64; tolerance = 0.612) met those criteria. Thus, it can be concluded that multicollinearity was not observed among the variables of this study.

The path analysis, including all the assumed relationships in the conceptual model (Figure 1), did not yield acceptable fit values. After removing the insignificant paths from the path analysis, a final model with acceptable fit values was developed (RMSEA = .086; chi-square = 15.21; df = 10; p-value = .12; NFI = .96; NNFI = .97; CFI = .98; SRMR = .057; GFI = .94; AGFI = .84). Figure 2 displays the model.

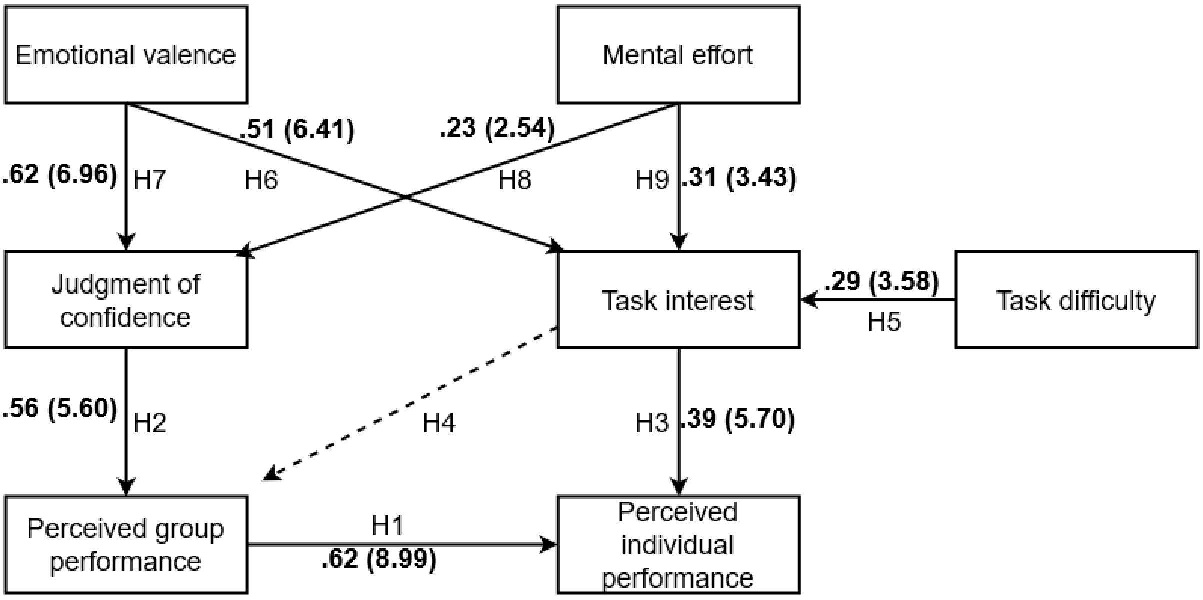

Fig. 2. Path model results. Solid arrows indicate significant paths. Dashed arrows indicate insignificant paths. Standardized estimates (t-values) are provided beside each arrow.

Path analysis results revealed a positive relationship between perceived group performance and perceived individual performance, supporting H1. Confirming H2, a positive relationship was found between judgment of confidence on group goal attainment and perceived group performance. Task interest was related to perceived individual performance but not to perceived group performance. Thus, H3 was supported and H4 is rejected. As hypothesized in H5, task interest was also positively related to task difficulty, showing that increased task difficulty served to increased task interest. Emotional valence was related to both task interest and judgment of confidence on group goal attainment. Thus, H6 and H7 were supported. Supporting H8 and H9, mental effort was related to judgment of confidence and task interest.

4.2. The relationship between group-level metacognitive experiences and objective group CPS performance

Metacognitive experiences were measured at the individual level, whereas the Tailorshop trend score was measured at the group level. Thus, to calculate group-level scores for each measurement of judgment of confidence, mental effort, task interest, task difficulty, and emotional valence, the best linear unbiased predictor method (Croon & Van Veldhoven, 2007) in the MicroMacroMultilevel R package (Lu, Page-Gould, & Xu, 2017) was used. Then, a generalized estimating equation (GEE) was run to investigate the extent to which judgment of confidence, mental effort, task interest, task difficulty, and emotional valence predicted objective group performance. GEE is a suitable method for analyzing the relationships between repeated measures because it considers the dependency of repeated measures with a working correlation structure and produces robust standard errors against misspecification of the correlation matrix (Paalman et al., 2015; Twisk, 2003). A GEE with an independent correlation structure and a covariance matrix with a robust estimator was run using SPSS21 software. The dependent variables were continuous, so a GEE model with a “normal” distribution and “log” function was tested (Morales, Grineski, & Collins, 2017). In our study, metacognitive experiences were measured with questionnaires with different scale points. GEE in SPSS does not provide standardized coefficient scores, so the metacognitive experiences scores were standardized prior to the GEE analysis, rendering it possible to compare the influences of metacognitive experiences on the dependent variable. The GEE results showed that groups’ collective mental effort, judgment of confidence, and emotional valence significantly predicted objective group CPS performance. The relationship between mental effort and objective group CPS performance was negative, while it was positive for judgment of confidence and emotional valence. No relationship was found between task interest, task difficulty, and objective group CPS performance. Table 3 presents the results: the strongest predictor of objective group CPS performance was the groups' collective mental effort, followed by emotional valence and judgment of confidence.

Table 3
GEE results predicting objective group CPS performance (*n* = 26 groups)

	B	S.E	Confidence interval		Wald Chi-Square	p
Mental effort	-0.425	0.1576	-0.734	-0.116	7.263	0.007
Task interest	0.061	0.2208	-0.372	0.494	0.076	>.05
Task difficulty	-0.079	0.1058	-0.286	0.128	0.558	>.05
Judgment of confidence	0.349	0.1724	0.011	0.687	4.093	0.043
Emotional valence	0.362	0.1153	0.136	0.588	9.852	0.002

5. Discussion

This study investigates the relationships between metacognitive experiences and performance in CPS. The study is concerned with both perceived performance and objective group performance. Overall, the current findings showed that emotional valence and mental effort are indicators of increased task confidence and interest within the group members. Perceived group performance was influenced by judgment of confidence, whereas perceived individual performance was influenced by task interest. A direct relationship was observed between perceived group and individual performance. Further, task difficulty had a positive impact on increased task interest. Mental effort, judgment of confidence, and emotional valence significantly predicted objective group performance in the simulation.

5.1. Metacognitive experiences, emotional valence, and self-reported performance in CPS

The path analysis showed a significant relationship between perceived group and individual performance (H1). That is, individuals' higher rating of their group's performance was associated with a higher rating of their own individual performance within the group. It has been found that an individual's performance in interdependent collaborative tasks relies heavily on the whole group's performance (Lindsley et al., 1995), and our findings support this. Interdependency in this study was realized through holding all the group members responsible for the CPS outcome. The findings showed that succeeding or failing as a group created a shared responsibility and accountability among the team members. Consequently, team members claimed ownership for the success or failure in the CPS task and based their individual achievement beliefs on the whole group's achievement beliefs. In this regard, the current findings underline the reciprocity of perceived individual and group performance in CPS.

We found that judgment of confidence about group goal attainment contributed to perceived group performance (H2). Confidence judgments about performance comprise a key subjective experience in self-regulated learning (Hadwin & Webster, 2013). Accurate judgments are important for choosing the optimum self-regulatory processes to reach task goals, while inaccurate judgments, in the form of overconfidence or underconfidence, may hinder regulation and achievement (Cavalcanti & Sibbald, 2014). It is common for learners to judge their performance inaccurately against the perceived standards (Bol & Hacker, 2001; Klassen, 2002). One way to scaffold learners in making accurate judgments is to provide them with feedback about their progress during a task, which can serve as a monitoring cue for triggering necessary regulatory processes and adapting group efforts to reach set standards (de Bruin et al., 2017). In our study, the CPS simulation informed participants about their group progress at specific intervals. It can be assumed that such feedback allowed participants to review their strategies in dealing with the problem situation through negotiation with their group members (Author et al., 20XX). Consequently, negotiation of group progress in relation to the feedback may have yielded a positive correlation between confidence judgments and perceived group performance.

Studies in individual learning settings have reported a positive relationship between task interest and learning performance (Eccles, 2009). We hypothesized that individuals with higher task interest would better regulate the group's progress and produce higher performance outcomes in CPS. Thus, high task interest could lead to increases in both perceived individual performance (H3) and perceived group performance (H4). Contrary to our expectations, task interest was related to perceived individual performance but not to perceived group performance. These findings can be explained by the influential role of shared regulatory processes in CPS. Effective collaboration is achieved when individuals regulate their team members' performance and their own performance through productive interactions (Hadwin et al., 2017). Productive interactions include the negotiation and alignment of task representations and goals with various cognitive, motivational, emotional, and metacognitive processes (Author et al., 20XX). Our findings imply that, as a metacognitive experience alone, individual task interest may not be sufficient to alter group dynamics and activate effective shared regulatory processes to succeed in CPS. Other group-level cognitive, motivational, and emotional processes may be more influential than task interest is in terms of perceived group performance. However, the significant relationship between task interest and perceived individual performance indicates that if an individual finds the CPS task interesting, he or she may invest more effort regardless of other group members, which may lead to the higher rating of individual performance in CPS.

A significant relationship was found between task difficulty and task interest (H5). Previous studies have shown that learners find difficult tasks more interesting than simple tasks (Schraw, 1997; Silvia, 2001). The current results are in accordance with those findings. Our findings can be explained by Vygotsky's (1978) "zone of proximal development" theory, which asserts that effective learning and development occur when individuals are presented with learning tasks that are beyond their current capabilities. In relation to CPS, task difficulty should be high enough to push learners to work together; there is no need for them to collaborate if they can accomplish the task alone (Iiskala et al., 2004). Difficult tasks activate higher levels of shared metacognitive processes in CPS than simple tasks do (Efklides et al., 1998b; Iiskala et al., 2004). Thus, it can be concluded that task difficulty is an important factor in triggering task interest in CPS.

Several studies have reported significant relationships between emotional valence and task interest. For example, Fulmer and Tullis (2013) found a significant covariance between emotional valence and task interest in students' reading fluency. Similarly, various studies have found significant relationships between emotional valence and task interest in text comprehension (Ainley et al.; 2005). Findings have also shown that the relationship between emotional valence and task interest was more apparent when reading difficult texts (Fulmer, D'Mello, Strain, & Graesser, 2015). Extending those findings to CPS, our study showed that positive emotions serve to increase task interest during collaborative work (H6). It can be argued that if the group successfully progresses in CPS, this is reflected through positive emotions, which then lead to increased task interest.

Emotional valence positively predicted judgment of confidence on group goal attainment (H7). The research on metacognition in different domains and age groups has revealed that feelings play a critical role in developing metacognitive judgments (Koriat & Levy-sadot, 2000). For example, in a study dealing with a high school physics course, positive emotions (e.g., hope) were positively related to self-efficacy judgments and metacognitive monitoring (González, Fernández, & Paoloni, 2017). Webster and Hadwin (2015) studied an undergraduate course on self-regulated learning and found that negative emotions were related to decreased confidence judgments about the achievement of individual learning goals. Significant relationships were also reported between emotions and metacognitive judgments in math problem solving among primary school students (Tornare et al., 2015). Supporting such findings, Greifeneder, Bless, and Pham (2011) found that individuals commonly use their emotions as an information source when making metacognitive judgments. In line with the literature, our findings showed that emotional valence plays a critical role in guiding confidence judgments in CPS. Thus, it can be concluded that metacognitive judgments are not only information based (e.g., feedback) but also dependent on learners' subjective feelings.

We found that mental effort positively predicted judgments of confidence (H8). These findings corroborate studies that found a positive relationship between perceived effort and metacognitive judgments in goal-driven learning situations (Koriat et al., 2014). Blisset and colleagues (2018) reported a negative relationship between metacognitive judgments and mental effort invested in an electrocardiography diagnosis task, but participants were not provided with any feedback about the accuracy of their judgments. In our study, participants reported their judgment of confidence in group goal attainment in relation to the feedback provided by the simulation. Thus, it can be assumed that the relationship between mental effort and judgment of confidence might become positive in CPS situations in which participants are provided a clear goal to achieve and continuous feedback about their task progress. Future experimental studies should test this assumption by comparing CPS conditions with and without feedback.

Mental effort can be an indicator of task motivation (Feldon et al., 2018; Likourezos & Kalyuga, 2017). In line with such findings, mental effort positively predicted task interest in our study (H9). Our findings show that presenting complex CPS tasks that impose high levels of cognitive load can push individuals to collaborate with their team members in order to deal with the complexity of the problem situation. In such a context, expending high mental effort in the collaborative task may be related to continuing task interest and persistence in the task (Schnotz, Fries, & Horz, 2009). The current findings contribute to two theoretical views on mental effort. The first considers motivation to be a precursor of mental effort (Rheinberg, Vollmeyer, & Burns, 2001). The second considers mental effort to be a function of task complexity and learner's expertise (Schnotz et al., 2009). Extending both views, our study shows that motivation (i.e., task interest) can also be influenced by mental effort in CPS.

5.2. Group metacognitive experiences and objective group CPS performance

Our findings reveal a significant and negative relationship between mental effort and objective group CPS performance. This finding can be explained by the effect of feedback valence on the mental effort rating. Raaijmakers and colleagues (2017) found that ratings of mental effort are higher if individuals are provided with negative rather than positive feedback about their task performance. (Efklides, 2002a; Efklides et al., 2006) also reported that the amount of mental effort invested is determined by the outcome produced during an ongoing task. If the outcome is not sufficient to meet the task goals, individuals invest more mental effort. By contrast, they invest less mental effort if their progress toward the goals unfolds smoothly. Therefore, it can be claimed that increased mental effort during a task might be related to poor CPS performance. This assumption is also supported by cognitive load theory, which asserts that human cognitive architecture is composed of long-term and working memory (Van Merrienboer & Sweller, 2005). The working memory can only process a few chunks of novel information, but it is not limited in processing information that is stored in the long-term memory. Experts have more organized knowledge (i.e., complex schemas) in their long-term memory than novices do (Kalyuga, 2007). These complex schemas allow experts to process more information in their working memory with less effort (Van Merrienboer & Sweller, 2005). Thus, the mental effort required to complete a specific task depends on the learners' expertise. The implication is that if a group gains expertise through figuring out the relationships between the variables in a complex problem situation, it will invest less mental effort on the task yet perform better.

A positive relationship was found between groups' collective judgment of confidence and objective CPS performance. The current findings also indicate a match between confidence judgment and both perceived and objective group CPS performance. Metacognitive judgments are inferential, and individuals base these judgments (i.e., confidence judgments) on a variety of monitoring cues (i.e., information sources; Koriat, 2015). It is common for individuals to misinterpret the cues and make inaccurate judgments about their task performance (Ackerman & Goldsmith, 2011; Hattie, 2013). Research has shown that monitoring cues presented to learners in the form of online feedback during the task might help them to make accurate judgments (Ariel, Dunlosky, & Bailey, 2009; Koriat et al., 2006). Supporting such findings, we found that complex problem-solving simulations (e.g., Tailorshop) that provide performance feedback during CPS may help learners to make accurate judgments about their task success.

The current findings show that positive group emotions were related to increased objective group performance in CPS. Several meta-analyses have reported a significant relationship between emotional valence and learning achievement in educational settings (Götz & Hall, 2013; Loderer, Pekrun, & Lester, 2018). Positive emotions contribute to better academic achievement by activating self-regulatory processes, such as deep learning strategies (Ahmed, der Werf, Kuyper, & Minnaert, 2013; Ranellucci, Hall, & Goetz, 2015). On the other hand, negative emotions were found to be detrimental to self-regulatory processes and achievement (Pekrun, Hall, Goetz, & Perry, 2014). In line with such results, our findings showed that a positive emotional climate among team members that is reflected as positive emotional valence led to higher CPS performance. However, emotional climate in our study may not have been limited to the social interactions among the team members. Cognitive interactions (e.g., planning, and strategy development) among the members during CPS might also contribute to the development of positive emotions. In our study, groups could observe the effectiveness of their cognitive strategies through the feedback presented by the simulation. Positive feedback has a positive influence on metacognitive experiences (Efklides, 2004; Efklides & Dina, 2004). Thus, the simulation's feedback may have influenced the emotional valence of the group members as well. Future research should investigate how positive emotions based on social interactions or cognitive interactions impact group success in CPS.

Task difficulty was not related to objective group CPS performance. Efklides and colleagues (2006) also found that task difficulty and task performance may be unrelated in very difficult tasks. The CPS simulation in our study involved complex relationships between its variables, meaning that it may be classified as a very difficult task. One possible explanation for the insignificant relationship between task difficulty and objective group CPS performance may be that the groups had no time limitation for the CPS task. Thus, it can be assumed that the groups had sufficient time to discover the relationships among the variables in the CPS simulation, no matter how difficult it was. Group CPS success may therefore rely on shared efforts and strategies rather than task difficulty if there is no time limit.

Finally, no relationship was observed between task interest and objective group performance. Task interest refers to the extent that one enjoys or values performing a task (Cleary & Chen, 2009), and it includes an affective dimension. Thus, a positive association can be expected between task interest and emotions (Efklides et al., 2018). Supporting this assumption, the existing study found a strong correlation between task interest and emotions (see Table 1). Our path analysis also showed that emotions contribute significantly to task interest (Figure 2). However, only emotions were found to be related to CPS performance. Thus, it can argued that emotions explain a significant amount of variance in task interest, which might confound the relationship between task interest and CPS performance.

5.3. Theoretical implications and the significance of the study

Metacognitive experiences are innately individual and subjective (Iiskala et al., 2011), but they are affected by the task content and context (Koriat & Levy-sadot, 2000). Thus, it is important to study metacognitive experiences in social settings to observe how these emerge in group contexts (Efklides, 2006). However, research on metacognitive experiences has been mostly conducted in individual learning environments. The few studies that have investigated metacognitive experiences in a collaborative setting have reported that metacognitive experiences facilitated socially shared metacognition (Iiskala et al., 2011). Metacognitive monitoring fuels the regulation of learning in collaborative groups (Hadwin et al., 2017), but little is known about the interplay of metacognitive experiences during collaboration. The current study thus addresses a significant gap in the literature by focusing on the relationships between metacognitive experiences and performance outcomes in CPS.

Traditionally, metacognition research was limited to cognitive processes in learning (Dinsmore et al., 2008). The current study contributes to the growing body of research that addresses the interactions between metacognition and affect by investigating the relationship between cognitive and affective metacognitive experiences. Specifically, our findings show that confidence judgments are related to emotional valence and mental effort, indicating that confidence judgments are based on both cognitive and emotional experiences during CPS.

Individuals often fail to apply effective regulatory strategies during collaboration (Barron, 2003). One reason for this is inaccurate judgment (i.e., monitoring) about ongoing performance (Dunlosky & Rawson, 2012). It has been found that learners can easily base their metacognitive judgments on momentary heuristics rather than effortful monitoring (Kahneman, 1973; Koriat, 2007). Providing feedback during a task may prompt learners with regard to task-specific monitoring processes and facilitate accurate judgments about the task performance (Hattie & Timperley, 2007; Sun et al., 2020). Therefore, effective feedback should be embedded in collaborative learning to foster successful team collaboration and effective monitoring. The current study utilized a CPS simulation that provided continuous feedback during the collaborative task. Our findings show that feedback might decrease the discrepancy between confidence judgments and performance outcomes at both the individual and group levels. Thus, we suggest that computer-based CPS simulations with feedback features can foster effective regulation by activating relevant metacognitive experiences. Specifically, providing feedback on group performance outcomes in CPS might help group members to update their strategies in order to improve their performance. However, feedback in technology-enhanced learning environments need not be limited to performance outcomes. It can also be based on the interaction behaviors of the group members during CPS (Holland, Baghaei, Mathews, & Mitrovic, 2011). For example, several CPS environments have been developed in which group members can collaborate synchronously through a chat interface (Chang et al., 2017). Real-time analysis of such chat dialogs with advanced computational methods (e.g., machine learning) can help to detect students' metacognitive experiences in different dimensions (e.g., cognitive, motivational, and emotional) (Bannert, Molenaar, Azevedo, Järvelä & Gašević, 2017). Based on the momentary analysis of students' metacognitive experiences, it might be also possible to support collaborating students in terms of effective regulation of cognitive, motivational, and emotional processes during CPS. Future research is necessary to explore this opportunity.

6. Limitations and future directions

The first limitation of this study concerns the CPS task. Metacognitive experiences in the current study were investigated in a highly complex CPS task. Thus, the findings might not be generalizable to CPS conditions that include different levels of task complexity. Further, the CPS task was running a business simulation. Therefore, the study findings might not be applicable to CPS tasks with different problem states. The second limitation lies in the sample. The participants were mostly postgraduate adult students, so the current findings may not be generalizable to younger populations at lower education levels. Furthermore, the sample size can be considered modest, although the path analysis results displayed good fit values. A larger sample size is suggested for future replications. The third limitation is related to the analytical method. This study employed established single-item self-report questionnaires to measure metacognitive experiences and emotions during CPS. However, perceived CPS performance was only measured at the end of the CPS task. Thus, the current findings display the overall relationships between metacognitive experiences, emotions, and perceived CPS performance rather than temporal covariations. Future studies could measure perceived CPS performance repeatedly along with the other variables of the study to address this limitation. The study featured a CPS task that included three participants in each group, but in a few groups, a participant had to leave before the task was finished. Those groups then completed the task in dyads. It is possible that some of the measures might have been influenced by the group size. A possible future work would be to study how metacognitive experiences are affected by group size in CPS. In addition, groups worked toward reaching an externally imposed goal. Future studies should explore how metacognitive experiences and emotions vary in CPS tasks in which groups have the autonomy to negotiate and decide on their own goals. Similarly, the existing study did not address the personality traits of group members, and future studies can explore how metacognitive experiences unfold in groups with regard to certain personality traits. Furthermore, this study did not focus on the temporal nature of social interactions among the group members. It would be interesting to investigate how specific shared processes (e.g., negotiation, conflicts, regulation, and argumentation) affect group members' metacognitive experiences. A key feature of collaborative work is that individuals receive feedback and support from others in the group, so the feedback provided to participants may not have been the only source of feedback affecting the performance score in the simulation. We suggest that the ways in which different feedback sources affect metacognitive experiences and performance in CPS be investigated. Finally, it is possible that asking participants to reflect about their metacognitive experiences during CPS with situated self-reports might have stimulated higher metacognition. Research on metacognitive prompting has shown that presenting students with generic reflective questions about their cognition and task progress might promote effective team collaboration and better performance (Newton, Wiltshire & Fiore, 2018; Wiltshire, Fiorella, & Fiore, 2014), but the empirical evidence on the issue is scarce. Therefore, a promising line of future research would be to investigate whether prompting students to reflect about their metacognitive experiences would affect team collaboration and performance in CPS.

7. Conclusion

Several conclusions can be drawn from the current findings. First, they provide further evidence that metacognitive experiences in CPS cannot be seen as separate constructs that are limited to the learners' individual metacognitive monitoring. Rather, they are socially constructed and intertwined subjective feelings and judgments that inform about the features of task progress and outcome in CPS. Therefore, studying metacognitive experiences in isolation would not be sufficient to elaborate the transactivity between cognitive, motivational, and emotional processes in social learning settings.

Second, we found that metacognitive judgments are based on cognitive (i.e., mental effort), affective (i.e., emotional valence), and external (i.e., feedback) cues derived from the learning context. These findings have implications for designing computer-based CPS simulations, which can facilitate accurate metacognitive judgments by providing learners with multiple metacognitive monitoring cues that draw learners' attention to the cognitive, affective, and external features of task processing.

Third, metacognitive experiences are inner subjective judgment and feelings. Thus, it has been questioned to what extent individual metacognitive experiences are expressed and shared among the group members (Efklides, 2006). The current study shows that metacognitive experiences measured at the individual level can be indicative of the objective group performance. It can be inferred that individual and group metacognition are linked, indicating that collective group experiences are developed through group members explicating and sharing their individual feelings and judgments with the others.

To conclude, metacognitive experiences are features of metacognitive monitoring that serve as online cues for activating regulatory loops necessary for successful learning. Understanding the interdependencies among the metacognitive experiences in CPS might help to develop learning designs and tools that facilitate effective metacognitive monitoring and self-regulated learning. The current study can be considered a preliminary attempt to unearth such interdependencies.

References

Ackerman, R., & Goldsmith, M. (2011). Metacognitive Regulation of Text Learning: On Screen Versus on Paper. *Journal of Experimental Psychology: Applied*, *17*(1), 18–32. https://doi.org/10.1037/a0022086

Ahmed, W., der Werf, G., Kuyper, H., & Minnaert, A. (2013). Emotions, self-regulated learning, and achievement in mathematics: A growth curve analysis. *Journal of Educational Psychology*, *105*(1), 150–161.

Ainley, M., Corrigan, M., & Richardson, N. (2005). Students, tasks and emotions: Identifying the contribution of emotions to students' reading of popular culture and popular science texts. *Learning and Instruction*, *15*(5), 433–447. https://doi.org/10.1016/j.learninstruc.2005.07.011

Ainley, M., Hidi, S., & Berndorff, D. (2002). Interest , Learning , and the Psychological Processes That Mediate Their Relationship, *94*(3), 545–561. https://doi.org/10.1037//0022-0663.94.3.545

Andrews-Todd, J., & Forsyth, C. M. (2018). Exploring social and cognitive dimensions of collaborative problem solving in an open online simulation-based task. *Computers in Human Behavior*. https://doi.org/https://doi.org/10.1016/j.chb.2018.10.025

Ariel, R., Dunlosky, J., & Bailey, H. (2009). Agenda-based regulation of study-time allocation: when agendas override item-based monitoring. *Journal of Experimental Psychology: General*, *138*(3), 432–447.

Aşık, G., & Erktin, E. (2019). Metacognitive experiences: Mediating the relationship between metacognitive knowledge and problem solving. *Egitim ve Bilim*, *44*(197), 85–103. https://doi.org/10.15390/EB.2019.7199

Baker, L., & Brown, A. L. (1984). Metacognitive skills and reading. In P. D. Pearson (Ed.), *Handbook of reading research*. New York: Longman.

Baker, K., Greenberg, S., & Gutwin, C. (2001). Heuristic evaluation ofgroupware based on the mechanics of collaboration. In *Paper presented at the Engineering for Human-Computer Interaction: 8th IFIP International Conference*. Toronto, Canada: EHCI 2001.

Bakhtiar, A., Webster, E. A., & Hadwin, A. F. (2018). Regulation and socio-emotional interactions in a positive and a negative group climate. *Metacognition and Learning*, *13*(1), 57–90.

Bandura, A. (1997). *Self-Efficacy: The exercise of control*. New York: Freeman.

Bannert, M., Molenaar, I., Azevedo, R., Järvelä, S. & Gašević, D. (2017). Relevance of learning analytics to measure and support students' learning in adaptive educational technologies. *Proceedings of the Seventh International Learning Analytics & Knowledge Conference*, pp. 568-569. ACM.

Barron, B. (2003). When Smart Groups Fail. *Journal of the Learning Sciences*. https://doi.org/10.1207/S15327809JLS1203_1

Barsade, S. G., & Gibson, D. E. (2012). Group affect: Its influence on individual and group outcomes. *Current Directions in Psychological Science, 21*(2), 119-123.

Barth, C. M., & Funke, J. (2010). Negative affective environments improve complex solving performance. *Cognition and Emotion*, *24*(7), 1259–1268.

Bergin, D. A. (2016). Social influences on interest. *Educational Psychologist, 51*(1), 7-22.

Blissett, S., Sibbald, M., Kok, E., & van Merrienboer, J. (2018). Optimizing self-regulation of performance: is mental effort a cue? *Advances in Health Sciences Education*, *23*(5), 891–898. https://doi.org/10.1007/s10459-018-9838-x

Boekaerts, M., & Rozendaal, J. S. (2010). Using multiple calibration indices in order to capture the complex picture of what affects students' accuracy of feeling of confidence. *Learning and Instruction*, *20*(5), 372–382.

Bol, L., & Hacker, D. (2001). A comparison of the effects of practice tests and traditional review on performance and evaluation. *The Journal of Experimential Education*, *69*, 133–144.

Brown, A. L. (1978). Knowing when, where, and how to remember: a problem of metacognition. In R. Glaser (Ed.), *Advances in instructional psychology*, *Vol.* 1 (pp. 77-165). Hillsdale, NJ: Erlbaum.

Brown, A. L. (1987). Metacognition, executive control, self-regulation and other mysterious mechanisms. In F. Weinert, & R. Kluwe (Eds.), *Metacognition, motivation and understanding* (pp. 65–115). Hillsdale, NJ: Lawrence Erlbaum.

Butler, D. L., & Winne, P. H. (1995). Feedback and self-regulated learning: A theoretical synthesis. *Review of Educational Research*, *65*(3), 245–281.

Care, E., Scoular, C., & Griffin, P. (2016). Assessment of collaborative problem solving in education environments. *Applied Measurement in Education*, *29*(4), 250-264.

Cavalcanti, R. B., & Sibbald, M. (2014). Am I right when I am sure? Data consistency influences the relationship between diagnostic accuracy and certainty. *Academic Medicine*, *89*(1), 107–113.

Chang, C. J., Chang, M. H., Chiu, B. C., Liu, C. C., Chiang, S. H. F., Wen, C. T., ... & Wu, S. W. (2017). An analysis of student collaborative problem solving activities mediated by collaborative simulations. *Computers & Education*, *114*, 222-235.

Chen, A., Darst, P. W., & Pangrazi, R. P. (1999). What constitutes situational interest? Validating a construct in physical education. *Measurement in Physical Education and Exercise Science*, *3*(3), 157–180. https://doi.org/10.1207/s15327841mpee0303_3

Clark, R. E. (1999). Yin and yang cognitive motivational processes operating in multimedia learning environments. In J. van Merrienböer (Ed.), *Cognition and multimedia design* (pp. 73–107). Herleen, Net herlands: Open University Press.

Cleary, T. J., & Chen, P. P. (2009). Self-regulation, motivation, and math achievement in middle school: Variations across grade level and math context. *Journal of School Psychology*, *47*(5), 291–314. https://doi.org/10.1016/j.jsp.2009.04.002

Croon, M. A., & Van Veldhoven, M. J. P. M. (2007). Predicting group-level outcome variables from variables measured at the individual level: A latent variable multilevel model. *Psychological Methods*, *12*(1), 45–57. https://doi.org/10.1037/1082-989X.12.1.45

Csikszentmihalyi, M. (1975). *Beyond Boredom and Anxiety: The Experience of Flow in Work and Play*. *Beyond Boredom and Anxiety: The Experience of Flow in Work and Play*. https://doi.org/10.2307/2065805

Danner, D., Hagemann, D., Schankin, A., Hager, M., & Funke, J. (2011). Beyond IQ: a latent state-trait analysis ofgeneral intelligence, dynamic decision making, and implicit learning. *Intelligence*, *39*, 323–334.

de Bruin, A. B. H., Dunlosky, J., & Cavalcanti, R. B. (2017). Monitoring and regulation of learning in medical education: the need for predictive cues. *Medical Education*, *51*(6), 575–584. https://doi.org/10.1111/medu.13267

de Bruin, A. B., & van Gog, T. (2012). Improving self-monitoring and self-regulation: From cognitive psychology to the classroom. *Learning and Instruction*, *24*(2), 245-252.

Dierdorff, E. C., & Ellington, J. K. (2012). Members matter in team training: Multilevel and longitudinal relationships between goal orientation, self-regulation, and team outcomes. *Personnel Psychology*, *65*(3), 661-703.

Dinsmore, D. L., Alexander, P. A., & Loughlin, S. M. (2008). Focusing the conceptual lens on metacognition, self-regulation, and self-regulated learning. *Educational Psychology Review*, *20*, 391–408.

Dobao, A. F., & Blum, A. (2013). Collaborative writing in pairs and small groups: Learners' attitudes and perceptions. *System*, *41*(2), 365-378.

Dohn, N. B. (2013). Upper secondary students' situational interest: A case study of the role of a zoo visit in a biology class. *International Journal of Science Education*, *35*(16), 2732-2751.

Dörner, D., Kreuzig, H. W., Reither, F., & Stäudel, T. (1983). *Lohhausen. Vom Umgang mit Komplexität [Lohhausen: On dealing with uncertainty and complexity].*

Dunlosky, J., & Metcalfe, J. (2009). *Metacognition*. Thousand Oaks, CA: Sage Publications, Inc.

Dunlosky, J., & Rawson, K. A. (2012). Underconfidence produces underachievement: Inaccurate self evaluations undermine students? learning and retention. *Learning and Instruction*, *22*, 271–280. https://doi.org/10.1016/j.learninstruc.2011.08.003

Eccles, J. (2009). Who am i and what am i going to do with my life? Personal and collective identities as motivators of action. *Educational Psychologist*, *44*(2), 78–89. https://doi.org/10.1080/00461520902832368

Eccles, J., & Wigfield, A. (2002). Motivational beliefs, values, and goals. *Annual Review of Psychology*, *53*(1), 109–132.

Efklides, A. (2001). Metacognitive Experiences in Problem Solving. In A. Efklides, J. Kuhl, & R. M. Sorrentino (Eds.), *Trends and Prospects in Motivation Research* (pp. 297–323). Dordrecht, Netherlands: Kluwer Academic Publishers. https://doi.org/10.1007/0-306-47676-2_16

Efklides, A. (2002a). Feelings as subjective evaluations of cognitive processing: How reliable are they? *Psychology: The Journal Ofthe Hellenic Psychological Society*, *9*, 163–184.

Efklides, A. (2002b). The systemic nature of metacognitive experiences: Feelings, judgments, and their interrelations. In P. C. Izaute & P.-J. Marescaux (Eds.), *Metacognition: Process, function, and use* (pp. 19–34). Dordrecht, The Netherlands: Kluwer.

Efklides, A. (2006). Metacognition and affect: What can metacognitive experiences tell us about the learning process? *Educational Research Review*, *1*(1), 3–14. https://doi.org/10.1016/j.edurev.2005.11.001

Efklides, A. (2008). Metacognition: Defining its facets and levels of functioning in relation to self-regulation and co-regulation. *European Psychologist*, *13*(4), 277-287.

Efklides, A. (2009). The role of metacognitive experiences in the learning process, *21*, 76–82.

Efklides, A. (2011). Interactions of metacognition with motivation and affect in self-regulated learning: The MASRL model. *Educational Psychologist*, *46*(1), 6–25. https://doi.org/10.1080/00461520.2011.538645

Efklides, A., & Dina, F. (2004). Efklides1B.Pdf. *Hellenic Journal of Psychology*, *1*, 179–202.

Efklides, A., Kourkoulou, A., Mitsiou, F., & Ziliaskopoulou, D. (2006). Metacognitive knowledge of effort, personality factors, and mood state: Their relationships with effort-related metacognitive experiences. *Metacognition and Learning*, *1*(1), 33–49. https://doi.org/10.1007/s11409-006-6581-0

Efklides, A., Papadaki, M., Papantoniou, G., & Kiosseoglou, G. (1998a). Individual differences in feelings of difficulty: The case of school mathematics. *European Journal of Psychology of Education*, *13*(2), 207–226. https://doi.org/10.1007/BF03173090

Efklides, A., Papadaki, M., Papantoniou, G., & Kiosseoglou, G. (1998b). Individual differences in feelings of difficulty: The case of school mathematics. *European Journal of Psychology of Education*, *13*(2), 207–226.

Efklides, A., & Petkaki, C. (2005). Effects of mood on students' metacognitive experiences. *Learning and Instruction*, *15*(5), 415–431. https://doi.org/10.1016/j.learninstruc.2005.07.010

Efklides, A., Schwartz, B. L., & Brown, V. (2018). Motivation and affect in self-regulated learning: Does metacognition play a role. In J. A. G. D. H. Schunk (Ed.), *Handbook of self-regulation of learning and performance* (pp. 64–82). Routledge.

Feldon, D. F., Callan, G., Juth, S., & Jeong, S. (2019). Cognitive Load as Motivational Cost, (1).

Flavell, J. (1979). Metacognition and cognitive monitoring: A new area of cognitive–developmental inquiry. *American Psychologist*, *34*, 906–911.

Feldon, D. F., Franco, J., Chao, J., Peugh, J., & Maahs-Fladung, C. (2018). Self-efficacy change associated with a cognitive load-based intervention in an undergraduate biology course. *Learning and Instruction*, *56*(April 2017), 64–72. https://doi.org/10.1016/j.learninstruc.2018.04.007

Fulmer, S. M. ., & Tulis, M. (2013). Changes in interest and affect during a difficult reading task: Relationships with perceived difficulty and reading fluency. *Learning and Instruction*, *27*, 11–20. https://doi.org/10.1016/j.learninstruc.2013.02.001

Fulmer, S. M., D'Mello, S. K., Strain, A., & Graesser, A. C. (2015). Interest-based text preference moderates the effect of text difficulty on engagement and learning. *Contemporary Educational Psychology*, *41*, 98–110.

González, A., Fernández, M. V. C., & Paoloni, P. V. (2017). Hope and anxiety in physics class: Exploring their motivational antecedents and influence on metacognition and performance. *Journal of Research in Science Teaching*, *54*(5), 558-585.

Goos, M., Galbraith, P., & Renshaw, P. (2002). Socially mediated metacognition: Creating collaborative zones of proximal development in small group problem solving. *Educational Studies in Mathematics*, *49*, 193–223

Graesser, A. C., Dowell, N., Hampton, A. J., Lippert, A. M., Li, H., & Shaffer, D. W. (2018). Building intelligent conversational tutors and mentors for team collaborative problem solving: Guidance from the 2015 Program for International Student Assessment. In *Building intelligent tutoring systems for teams: What matters* (pp. 173-211). Emerald Publishing Limited.

Greifeneder, R., Bless, H., & Pham, M. T. (2011). When do people rely on affective and cognitive feelings in judgment? A review. *Personality and Social Psychology Review*, *15*(2), 107-141.

Götz, T., & Hall, N. C. (2013). Emotion and achievement in the classroom. In J Hattie (Ed.), *International guide to student achievement* (pp. 192–195). London: Routledge.

Hadwin, A. F., Järvelä, S., & Miller, M. (2017). Self-regulation, co-regulation and shared regulation in collaborative learning environments. In D. H. Schunk & J. A. Greene (Eds.), *Handbook of self-regulation of learning and performance* (pp. 83–106). New York: Routledge.

Hadwin, A. F., & Webster, E. A. (2013). Calibration in goal setting : Examining the nature of judgments of con fi dence. *Learning and Instruction*, *24*, 37–47. https://doi.org/10.1016/j.learninstruc.2012.10.001

Hair, J. F., Black, W. C., Babin, B. J., & Anderson, R. E. (2009). *Multivariate Data Analysis 7th Edition*. Essex: Pearson Prentice Hall.

Hattie, J, & Timperley, H. (2007). The power of feedback. *Review of Educational Research*, *77*(1), 81–113.

Hamilton, K., Mancuso, V., Mohammed, S., Tesler, R., & McNeese, M. (2017). Skilled and Unaware: The Interactive Effects of Team Cognition, Team Metacognition, and Task Confidence on Team Performance. *Journal of Cognitive Engineering and Decision Making*, *11*(4), 382–395. https://doi.org/10.1177/1555343417731429.

Hattie, John. (2013). Calibration and confidence: Where to next? *Learning and Instruction*, *24*(1), 62–66. https://doi.org/10.1016/j.learninstruc.2012.05.009

He, Q., von Davier, M., Greiff, S., Steinhauer, E. W., & Borysewicz, P. B. (2017). Collaborative problem solving measures in the Programme for International Student Assessment (PISA). In A. von Davier, M. Zhu, & P. C. Kyllonen (Eds.), *Innovative assessment of collaboration* (pp. 95–111). Dordrecht, Netherlands: Springer.

Herborn, K., Stadler, M., Mustafić, M., & Greiff, S. (2018). The assessment of collaborative problem solving in PISA 2015: Can computer agents replace humans? *Computers in Human Behavior*, (January). https://doi.org/10.1016/j.chb.2018.07.035

Hesse, F., Care, E., Buder, J., Sassenberg, K., & Griffin, P. (2015). A framework for teachable collaborative problem solving skills. In *Assessment and teaching of 21st century skills* (pp. 37–56). Dordrecht, Netherlands: Springer.

Hidi, S. (2006). Interest: A unique motivational variable. *Educational Research Review, 1*(2), 69-82.

Holland, J., Baghaei, N., Mathews, M., & Mitrovic, A. (2011). The effects of domain and collaboration feedback on learning in a collaborative intelligent tutoring system. In International Conference on Artificial Intelligence in Education (pp. 469-471). Springer, Berlin, Heidelberg.

Hmelo-Silver, C. E., & Barrows, H. S. (2008). Facilitating Collaborative Knowledge Building. *Cognition and Instruction, 26*(1), 48-94. https://doi.org/10.1080/07370000701798495

Hmelo-Silver, C. E., Chernobilsky, E., & Jordan, R. (2008). Understanding collaborative learning processes in new learning environments. *Instructional Science, 36*(5-6), 409-430.

Iiskala, T. (2015). Socially shared metacognitive regulation during collaborative learning processes in student dyads and small groups.Unpublished dissertation thesis. Turky: University of Turku.

Iiskala, T., Vauras, M., & Lehtinen, E. (2004). Socially-shared metacognition in peer learning? *Hellenic Journal of Psychology, 1*, 147–178.

Iiskala, T., Vauras, M., Lehtinen, E., & Salonen, P. (2011). Socially shared metacognition of dyads of pupils in collaborative mathematical problem-solving processes. *Learning and Instruction*, *21*(3), 379–393. https://doi.org/10.1016/j.learninstruc.2010.05.002

Janssen, J., Erkens, G., Kirschner, P. A., & Kanselaar, G. (2012). Task-related and social regulation during online collaborative learning. *Metacognition and Learning*, *7*(1), 25–43. https://doi.org/10.1007/s11409-010-9061-5

Johnson, D. W., Maruyama, G., Johnson, R., Nelson, D., & Skon, L. (1981). Effects of cooperative, competitive, and individualistic goal structures on achievement: A meta-analysis. *Psychological Bulletin, 89*(1), 47.

Kahneman, D. (1973). *Attention and effort*. Englewood Cliffs, NJ: Prentice- Hall.

Kalyuga, S. (2007). Expertise reversal effect and its implications for learner-tailored instruction. *Educational Psychology Review*, *19*(4), 509–539.

Koriat, A. (1997). Monitoring one's own knowledge during study: A cue-utilization approach to judgments of learning. *Journal of experimental psychology: General, 126*(4), 349.

Klassen, R. (2002). A question of calibration: a review of the self-efficacy beliefs of students with learning disabilities. *Learning Disability Quarterly*, *25*, 88–102.

Koriat, A. (2007). Metacognition and consciousness. In P. D. Zelazo, M. Moscovitch, & E. Thompson (Eds.), *The Cambridge handbook of consciousness* (pp. 289–325). Cambridge, UK: Cambridge University Press.

Koriat, A. (2015). Metacognition: Decision-making processes in self-monitoring and self-regulation. In G. W. G. Keren (Ed.), *The Wiley Blackwell handbook of judgment and decision making* (pp. 356–379). Oxford, UK: John Wiley & Sons.

Koriat, A., & Levy-sadot, R. (2000). Conscious and Unconscious Metacognition : A Rejoinder, *202*, 193–202. https://doi.org/10.1006/ccog.2000.0436

Koriat, A., Ma'ayan, H., & Nussinson, R. (2006). The intricate relationships between monitoring and control in metacognition: Lessons for the cause-and-effect relation between subjective experience and behavior. *Journal of Experimental Psychology: General*, *135*(1), 36–69. https://doi.org/10.1037/0096-3445.135.1.36

Koriat, A., Nussinson, R., & Ackerman, R. (2014). Judgments of learning depend on how learners interpret study effort. *Journal of Experimental Psychology: Learning Memory and Cognition*, *40*(6), 1624–1637. https://doi.org/10.1037/xlm0000009

Ku, H. Y., Tseng, H. W., & Akarasriworn, C. (2013). Collaboration factors, teamwork satisfaction, and student attitudes toward online collaborative learning. *Computers in Human Behavior*, *29*(3), 922-929.

Kumar, S., & Jagacinski, C. M. (2011). Confronting task difficulty in ego involvement: Change in performance goals. *Journal of Educational Psychology*, *103*, 664–682.

Lajoie, S. P., Lee, L., Poitras, E., Bassiri, M., Kazemitabar, M., Cruz-Panesso, I., et al. (2015). The role of regulation in medical student learning in small groups: Regulating oneselfand others' learning and emotions. *Computers in Human Behavior, 52*, 601–616. doi:10.1016/j.chb.2014.11.073.

Likourezos, V., & Kalyuga, S. (2017). Instruction-first and problem-solving-first ap- proaches: Alternative pathways to learning complex tasks. *Instructional Science*, *45*, 195–219.

Lindsley, D. H., Brass, D. J., & Thomas, J. B. (1995). Efficacy-performance spirals: A multilevel perspective. *Academy of Management Review*, *20*(3), 645–678.

Loderer, K., Pekrun, R., & Lester, J. C. (2018). Beyond cold technology: A systematic review and meta-analysis on emotions in technology-based learning environments. *Learning and Instruction*, (July 2017), 1–15. https://doi.org/10.1016/j.learninstruc.2018.08.002

Lu, J. G., Page-Gould, E., & Xu, N. R. (2017). *MicroMacroMultilevel R package*.

Mangos, P. M., & Steele-Johnson, D. (2004). The Role of Subjective Task Complexity in Goal Orientation, Self-Efficacy, and Performance Relations. *Human Performance*, *14*(2), 169–185. https://doi.org/10.1207/s15327043hup1402_03

McCarthy, A., & Garavan, T. N. (2008). Team learning and metacognition: A neglected area of HRD research and practice. *Advances in Developing Human Resources*, *10*(4), 509-524.

Molenaar, I., van Boxtel, C. A., & Sleegers, P. J. (2011). Metacognitive scaffolding in an innovative learning arrangement. *Instructional Science*, *39*(6), 785-803.

Nelson, T. O., & Narens, L. (1990). Metamemory: A theoretical framework and new findings. In G. H. Bower (Ed.), *The psychology oflearning and motivation* (pp. 125–173). New York, NY: Academic Press.

Newton, O. B., Wiltshire, T. J., & Fiore, S. M. (2018). Macrocognition in teams and metacognition: Developing instructional strategies for complex collaborative problem solving. *Research on Managing Groups and Teams*, *19*, 33–54. https://doi.org/10.1108/S1534-085620180000019006.

Nussbaum, M., Alvarez, C., McFarlane, A., Gomez, F., Claro, S., & Radovic, D. (2009). Technology as small group face-to-face Collaborative Scaffolding. *Computers & Education*, *52*(1), 147-153.

Morales, D. X., Grineski, S. E., & Collins, T. W. (2017). Increasing research productivity in undergraduate research experiences: Exploring predictors of collaborative faculty-student publications. *CBE Life Sciences Education*, *16*(3), 1–9. https://doi.org/10.1187/cbe.16-11-0326

Nerantzaki, K., & Anastasia Efklides. (2019). Epistemic emotions: Interrelationships and changes during task processing. *Hellenic Journal of Psychology*, *16*(2), 177–199.

Nonose, K., Kanno, T., & Furuta, K. (2014). Effects of metacognition in cooperation on team behaviors. *Cognition, Technology & Work*, *16*(3), 349-358.

OECD. (2013). *PISA 2015 Collaborative Problem Solving Framework*. Retrieved from https://www.oecd.org/pisa/

Özcan, Z. Ç., & Eren Gümüş, A. (2019). A modeling study to explain mathematical problem-solving performance through metacognition, self-efficacy, motivation, and anxiety. *Australian Journal of*

Education, *63*(1), 116–134. https://doi.org/10.1177/0004944119840073.

Paalman, C., Van Domburgh, L., Stevens, G., Vermeiren, R., Van De Ven, P., Branje, S., … Doreleijers, T. (2015). Internalizing and externalizing problems in immigrant boys and girls: Comparing native Dutch and Moroccan immigrant adolescents across time. *International Journal of Behavioral Development*, *39*(3), 242–254. https://doi.org/10.1177/0165025414538554

Paas, F. G. (1992). Training strategies for attaining transfer of problem-solving skill in statistics: A cognitive-load approach. *Journal of Educational Psychology*, *84*, 429–434.

Pekrun, R., Frenzel, A., Goetz, T., & Perry, R. P. (2007). The control-value theory of achievement emotions: an integrative approach to emotions in education. In P. A. S. & R. Pekrun (Ed.), *Emotion in education* (pp. 13–36). San Diego, CA: Academic Press.

Pekrun, R., Goetz, T., Perry, R. P., Kramer, K., Hochstadt, M., & Molfenter, S. (2004). Beyond test anxiety: Development and validation of the Test Emotions Questionnaire (TEQ). *Anxiety, Stress & Coping*, *17*(3), 287–316.

Pekrun, R., Hall, N. C., Goetz, T., & Perry, R. P. (2014). Boredom and academic achievement: Testing a model of reciprocal causation. *Journal of Educational Psychology*, *106*(3), 696–710.

Pintrich, P. R., & De Groot, E. V. (1990). Motivational and self-regulated learning components of classroom academic performance. *Journal of Educational Psychology*, *82*(1), 33.

Putwain, D., Sander, P., & Larkin, D. (2013). Academic self-efficacy in study-related skills and behaviours: Relations with learning-related emotions and academic success. *British Journal of Educational Psychology*, *83*(4), 633–650. https://doi.org/10.1111/j.2044-8279.2012.02084.x

Raaijmakers, S. F., Baars, M., Schaap, L., Paas, F., & van Gog, T. (2017). Effects of performance feedback valence on perceptions of invested mental effort. *Learning and Instruction*, *51*, 36–46. https://doi.org/10.1016/j.learninstruc.2016.12.002

Raes, A., Schellens, T., De Wever, B., & Benoit, D. F. (2016). Promoting metacognitive regulation through collaborative problem solving on the web: When scripting does not work. *Computers in Human Behavior, 58*, 325-342.

Ranellucci, J., Hall, N. C., & Goetz, T. (2015). Achievement goals, emotions, learning, and performance: A process model. *Motivation Science*, *1*(2), 98–120.

Reiter-Palmon, R., Sinha, T., Gevers, J., Odobez, J.-M., & Volpe, G. (2017). Theories and models of teams and groups. *Small Group Research*, *48*(5), 1–24. https://doi.org/10.1177/1046496417722841.

Renninger, K. A., & Bachrach, J. E. (2015). Studying triggers for interest and engagement using observational methods. *Educational Psychologist, 50*(1), 58-69.

Resnick, L. B. (1991). Shared cognition: Thinking as social practice. In L. B. Resnick, J. M. Levine, & S. D. Teasley (Eds.), *Perspectives on socially shared cognition* (pp. 1–20). Washington, DC: Routledge.

Rey, G. D., & Buchwald, F. (2011). The expertise reversal effect: Cognitive load and motivational explanations. *Journal of Experimental Psychology: Applied*, *17*(1), 33–48.

Rheinberg, F., Vollmeyer, R., & Burns, B. D. (2001). FAM: Ein Fragebogen zur Erfassung aktueller Motivation in Lern-und Leistungssituationen (Langversion, 2001). *Diagnostica*, *2*, 57–66.

Salonen, P., Vauras, M., & Efklides, A. (2005). Social interaction-what can it tell us about metacognition and coregulation in learning?. *European Psychologist, 10*(3), 199-208.

Schnotz, W., Fries, S., & Horz, H. (2009). Motivational aspects of cognitive load theory. In A. E. & P. N. M. Wosnita S. A. Karabenick (Ed.), *Contemporary motivation research: from global to local perspectives* (pp. 69–96). CAmbridge,MA: Hogrefe & Huber Publishers.

Schoor, C., Narciss, S., & Körndle, H. (2015). Regulation during cooperative and collaborative learning: A theory-based review of terms and concepts. *Educational Psychologist, 50*(2), 97-119.

Schraw, G. (1997). Situational interest in literary text. *Contemporary Educational Psychology*, *22*(4), 436–456.

Schunk, D. H., & Ertmer, P. A. (2000). Self-regulation and academic learning: Self-efficacy enhancing interventions. In P. P. Boekaerts & M. Zeidner (Eds.), *Handbook of self-regulation* (p. 631−649). Orlando, FL: Academic Press.

Schwarz, N (2015). Metacognition. In M. Mikulincer, P.R. Shaver, E. Borgida, & J. A. Bargh (Eds.), APA Handbook of Personality and Social Psychology: Attitudes and Social Cognition (pp. 203-229). Washington, DC: APA.

Schwarz, N., & Clore, G. L. (1996). Feelings of phenomenal experiences. In E. T. H. & A. Kruglanski (Ed.), *A Handbook of Basic Principles* (pp. 433–465). 433?465. New York: Guilford Press.

Silvia, P. J. (2001). Interest and interests: The psychology of constructive capriciousness. *Review of General Psychology, 5*, 270–290.

Slof, B., Erkens, G., Kirschner, P. A., Janssen, J., & Phielix, C. (2010). Fostering complex learning-task performance through scripting student use of computer supported representational tools. *Computers and Education*. https://doi.org/10.1016/j.compedu.2010.07.016

Slof, B., Erkens, G., Kirschner, P. A., Jaspers, J. G. M., & Janssen, J. (2010). Guiding students' online complex learning-task behavior through representational scripting. *Computers in Human Behavior*. https://doi.org/10.1016/j.chb.2010.02.007

Stajkovic, A. D., Lee, D., & Nyberg, A. J. (2009). Collective Efficacy, Group Potency, and Group Performance: Meta-Analyses of Their Relationships, and Test of a Mediation Model. *Journal of Applied Psychology*, *94*(3), 814–828. https://doi.org/10.1037/a0015659

Stewart, A., &, S. K. (2018, June). Connecting the dots towards collaborative AIED: Linking group makeup to process to learning. In *International Conference on Artificial Intelligence in Education* (pp. 545-556). Springer, Cham.

Sun, C., Shute, V. J., Stewart, A., Yonehiro, J., Duran, N., & D'Mello, S. (2020). Towards a generalized competency model of collaborative problem solving. *Computers & Education, 143*, 103672.

Tabachnick, B. G., & Fidell, L. S. (2007). *Using multivariate statistics (5th ed.)*. Boston: Pearson Education.

Tapola, A., Veermans, M., & Niemivirta, M. (2013). Predictors and outcomes of situational interest during a science learning task. *Instructional Science*, *41*(6), 1047–1064. https://doi.org/10.1007/s11251-013-9273-6.

Tornare, E., Czajkowski, N. O., & Pons, F. (2015). Children's emotions in math problem solving situations: Contributions of self-concept, metacognitive experiences, and performance. Learning and Instruction, 39, 88-96.

Twisk, J. W. R. (2003). *Applied longitudinal data analysis for epidemiology: A practical guide*. Cambridge, UK: Cambridge University Press.

Van Merrienboer, J. J., & Sweller, J. (2005). Cognitive load theory and complex learning: Recent developments and future directions. *Educational Psychology Review*, *17*(2), 147–177.

Volet, S., Vauras, M., Salo, A. E., & Khosa, D. (2017). Individual contributions in student-led collaborative learning: Insights from two analytical approaches to explain the quality of group outcome. *Learning and Individual Differences*, *53*, 79-92.

Volet, S., Vauras, M., & Salonen, P. (2009). Psychological and social nature of self- and co-regulation in learning contexts: an integrative perspective. *Educational Psychologist*, *44*(4), 215–226.

Webster, E. A., & Hadwin, A. F. (2015). Emotions and emotion regulation in undergraduate studying: examining students' reports from a self-regulated learning perspective. *Educational Psychology*, *35*(7), 794–818. https://doi.org/10.1080/01443410.2014.895292

Wigfield, A., & Eccles, J. S. (2000). Expectancy-value theory of achievement motivation. *Contemporary Educational Psychology*, *25*(1), 68–81.

Wiltshire, T. J., Rosch, K., Fiorella, L., & Fiore, S. M. (2014). Training for collaborative problem solv- ing: Improving team process and performance through metacognitive prompting. *Proceedings of 58th annual meeting of the human factors and ergonomics society* (pp. 1154?1158). Santa Monica, CA: Human Factors and Ergonomics Society.

Winne, P. H. (2010). Bootstrapping learner ' s self-regulated learning. *Psychological Test and Assessment Modeling*, *52*(4), 472–490.

Winne, P. H. (2019). Computers in Human Behavior Paradigmatic Dimensions of Instrumentation and Analytic Methods in Research on Self-Regulated Learning. *Computers in Human Behavior*, *96*, 285–289. https://doi.org/10.1016/j.chb.2019.03.026

Winne, P. H., & Hadwin, A. F. (1998). Studying as Self-Regulated Learning. *Metacognition in Educational Theory and Practice*. https://doi.org/10.1016/j.chb.2007.09.009

Zimmerman, B. J., & Schunk, D. H. (2011). *Self-regulated learning and performance: An introduction and an overview*. (B. Zimmerman & D. H. Schunk, Eds.), *Handbook of self-regulation of learning and performance*. New York: Routledge.