Coordinating Collaborative Problem-solving Processes by Providing Part-task Congruent Representations

Abstract: This study investigated whether structuring an online collaborative problem-solving task into part-tasks and providing part-task congruent representations supports students establishing and maintaining a shared understanding of the concepts, principles and procedures in the knowledge domain and negotiating about them. This better coordination of students' discussions was, in turn, expected to lead to better problem-solving performance. In triads secondary education students worked on a case-based business-economics problem in four conditions. In one condition, groups received three representations, each congruent to one of the three part-tasks. In the other three conditions, groups received one of the representations for all three part-tasks, thus a representation congruent to one part-task, but incongruent to the other two. The results show that coordination processes were indeed more suited. That is, students where better able to establish and maintain a shared understanding and to negotiate about it and, therefore, led to better problem-solving performance.

Introduction

Solving a complex problem is regarded as a sequenced phased process (i.e., problem orientation, problem solution, solution evaluation) in which each phase has its own specific purpose and where each phase requires a specific kind of interaction (Ploetzner, Fehse, Kneser, & Spada, 1999; Van Bruggen, Boshuizen, & Kirschner, 2003). Coping with the task demands of the different problem phases (i.e., part-tasks), requires students to actively engage in a process of sense-making of the knowledge domain by articulating and discussing multiple problem perspectives and problem-solving strategies. That is, students are required to carry out part-task related activities such as discussing the concepts, principles, and procedures of the domain (Barron, 2003; Hmelo-Silver, Duncan, & Chinn, 2007). Meaningful discussions about the domain can, however, hardly be achieved when students are not aware of each others' knowledge, ideas and do not negotiate about them with their peers. Students are required to activate their knowledge and skills and to establish and maintain a shared understanding of the domain; a common frame of reference where conflicting points of view be detected and negotiated. In this way collaborative learning situations require three main processes of coordination: (1) mutual activation and sharing of knowledge and skills, (2) grounding or creating a common frame of reference, and (3) negotiation or the process of coming to agreement (Erkens, Jaspers, Prangsma, & Kanselaar, 2005; Kirschner, Beers, Boshuizen, & Gijselaers, 2008). Research on Computer Supported Collaborative Learning (CSCL) has shown that representational tools can beneficially affect student interaction by providing external representations (see Fisher, Bruhn, Gräsel, & Mandl, 2002). First, an ER offers a restricted view of the knowledge domain, guiding the content-related interaction in a specific manner (Suthers, 2006). Second, in their discussions students can refer to the ER (i.e., deictic referencing), thereby supporting them to create a common frame of reference and facilitating a meaningful discussion (Suthers, Hundhausen, & Girardeau, 2003). These studies, though very valuable and informative, often neglect the fact that problem-solving tasks are usually composed of fundamentally different part-tasks that each require a different perspective on the knowledge domain. Therefore, multiple representational tools each containing a different external representation seem to be required. To be supportive for problem-solving, the external representation provided in the representational tool has to be matched to the part-task demands and activities of a specific problem phase. Otherwise, communication problems can occur and problem-solving performance might decrease (Van Bruggen, et al.).

The goal of the study presented in this paper is to twofold. On the one hand it is aimed at determining whether proper coordination processes can be evoked through providing part-task congruent guidance in the representational tools. On the other hand it is aimed at determining whether such an approach can lead to better problem-solving performance.

Coordination Processes

For meaningful discussion to arise, students must properly coordinate their discussions of the concepts, principles and procedures by carrying out communicative activities such as making their own knowledge and ideas explicit to other group members, focusing, checking and argumentation (Andriessen, Baker, & Suthers, 2003; Erkens, et al., 2005; Weinberger Ertl, Fischer, & Mandl, 2005). When made explicit, students must try to maintain a shared topic of discourse and to repair a common focus if they notice a focus divergence. Students coordinate their topic of discourse by *focusing*. Also, not all concepts, principles, and procedures are relevant for carrying out a part-task, thus, students have to guard the coherence and consistency of their shared understanding of the knowledge domain. By *checking*, students ground their communication in a common understanding, which was found to be one of the major communicative activities in dialogues of collaborative problem-solving and related to the quality of the problem solving process (Van der Linden, Erkens, Schmidt, & Renshaw, 2000). Furthermore, students must come to agreement with respect to relevant concepts principles and procedures. By *argumentation* they will try to change their partners viewpoint to arrive at the best way to carry out a part-task or at a definition of concepts acceptable for all. In this argumentation process they try to convince the other(s) by elaborating on their point of view, giving explanations, justifications and accounts (Erkens, et al.; Kirschner, et al., 2008). Only when students carry out such communicative activities their interaction can be sufficiently coordinated and multiple perspectives on the problem and the problem-solving strategy can arise.

Providing Part-task Congruent Representations

Due to its different part-tasks, problem-solving tasks require multiple representational tools providing different external representations. The specific ontology (i.e., objects, relations, rules for combining them) of each ER offers a restricted view of the knowledge domain (i.e., problem representations), guiding student interaction in a specific manner. To effectively do this, one must carefully match the external representation provided in a representational tool to the part-task demands and activities of a specific problem phase (Van Bruggen, et al., 2003). To ensure this alignment between tool, tool use and part-tasks scripting is employed (Dillenbourg, 2002; Weinberger, et al., 2005). According to Dillenbourg a script is “a set of instructions regarding to how the group members should interact, how they should collaborate and how they should solve the problem” (p. 64). Integrating scripting with the availability of representational tools sequences and makes the different part-task demands explicit so that they can be foreseen with part-task congruent guidance in the representational tools (see Table 1). By doing so, communicative activities beneficial for coordinating the collaborative problem-solving can be evoked.

Table 1: Congruence between external representation and part-task demands

Problem phase	Part-task demands	ER	Representational guidance
Problem orientation	Determining core concepts and relating them to the problem	Conceptual (static)	Showing concepts and their interrelationship
Problem solution	Proposing multiple solutions to the problem	Causal (static)	Showing causal relation between the concepts and possible solutions
Solution evaluation	Determining suitability of the solutions and coming to a final solution to the problem	Simulation (dynamic)	Showing mathematical relation betweenthe concepts and enabling manipulation of their value

Design and Expectations

This study focuses on whether providing part-task congruent support in the representational tools affects both students’ communicative activities and problem-solving performance in a CSCL-environment. In four experimental conditions, student triads had to collaboratively solve a case-based problem in business-economics that was divided into three problem phases each coupled with a different ER. To study the effect of condition, ERs were either matched or mismatched to the different problem phases; in other words they were either congruent or incongruent to the required task activities. In three mismatch conditions, groups received either a static ER (i.e., conceptual or causal ER) or a dynamic ER (i.e., simulation) that matched only one of the part-tasks. The scripting structured the problem-solving process in three phases, but only one of the ERs is available to the students for solving the problem yielding a phase-match when the ER matched one of the three phases and a mismatch for the other two phases. In the fourth condition, groups received all three ERs in a phased order receiving the ER most suited to each problem phase. Here, thus, there was a match between all three ERs and all three part-tasks. Due to the presumed match between ERs and part-tasks, student understanding and communicative activities were expected to increase, allowing the students to reach better problem solutions. It was, therefore, hypothesized that students in the match condition *(H1)* carry out more communicative activities beneficial for coordinating their collaborative problem-solving and *(H2)* have better problem-solving performance. In this paper, the focus will be on guiding student interaction when collaboratively solving a complex business economics problem. One should, therefore, take into account that the congruency of the content-related guidance was tailored to the part-task demands of this problem. The premise behind the design of the representational scripting and its use, however, can be generalized to all situations where a problem-solving task has a part-task structure.

Method

Participants

Participants were students from a business-economics class in a secondary education school in the Netherlands. The total sample consisted of 39 students (24 male, 15 female). The mean age of the students was 16.74 years (*SD* = .83, Min = 15, Max = 18). The students were randomly assigned to 13 triads divided between the four conditions; four triads in the conceptual and three triads in each of the other conditions (i.e., causal, simulation and match).

Problem-solving task and materials

CSCL-environment: Virtual Collaborative Research Institute

Students worked in a CSCL-environment called Virtual Collaborative Research Institute (VCRI, see Figure 1), a groupware application for supporting the collaborative performance of problem-solving tasks and research projects (Broeken, Jaspers, & Erkens, 2006). For this study, five VCRI tools were augmented with representational scripting. All tools, except the Notes tool, were shared among group members.

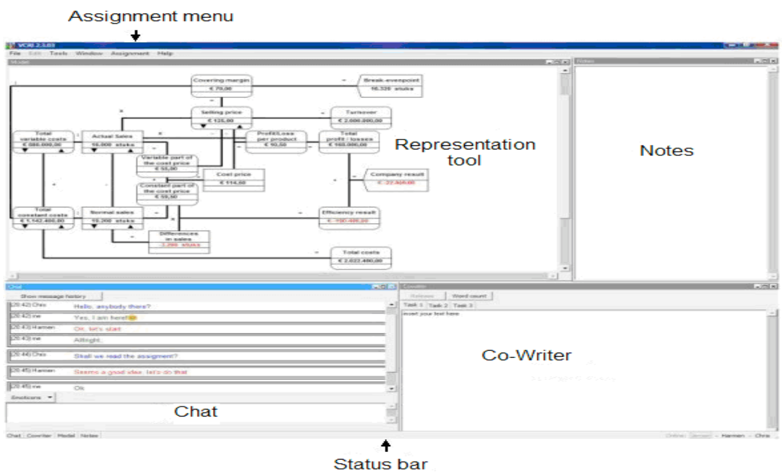

Figure 1. Screenshot of the VCRI-program.

The *chat tool* enables synchronous communication and supports students in externalizing and discussing their knowledge and ideas. The chat history is automatically stored and can be re-read by the students. In the *Assignment menu*, students can find the description of the problem-solving task / part-tasks. Besides this, additional information sources such as a definition list, formula list, and clues for solving the problem were also available here. The *Co-writer* is a shared text-processor where students can collaboratively formulate and revise their answers to the part-tasks. The *Notes tool* is an individual notepad that allows students to store information and structure their own knowledge and ideas before making them explicit. The *Status bar* is an awareness tool that displays which group members are logged into the system and which tool a group member is currently using. Students in all conditions had access to these tools and information sources. In other words, the different conditions were information equivalent and only differed in the way that the ERs are intended to guide the interaction.

Problem-solving task and part-task congruent representations

All groups worked on a case-based problem in business-economics in which they had to advise an entrepreneur about changing the business strategy to increase profits (i.e., company result). To come up with an advice, students had to carry out three different part-tasks, namely (1) determine the main factors affecting the company's result and relate them to the problem, (2) determine how certain interventions affect company result, and (3) compare the effects of these interventions and formulate a final advice based on this comparison. Through scripting, the problem-solving process was structured into a problem orientation phase, problem solution phase, solution evaluation phase each focusing on one of the part-tasks. All groups were 'forced' to carry out the part-tasks in a predefined order; they could only start with a new part-task after finishing an earlier part-task. When group members agreed that a part-task was completed, they had to 'close' that phase in the assignment menu. This 'opened' a new phase, which had two consequences for all groups, namely they (1) received a new part-task, and (2) had to enter their new answers in a different window of the Co-writer. All conditions received the part-tasks in the same order, but only groups in the match condition received a new ER.

The *problem orientation phase* focused on creating a global qualitative problem-representation by asking students to explain what they thought the problem was and to describe what the most important factors were that influenced the problem. During this phase, students received the conceptual ER (i.e., a static content scheme; see Figure 2) that made two aspects salient, namely the core concepts needed to carry out this part-task and, how the core concepts are qualitatively interrelated. Students could see that 'company result' is affected by the 'total profit' and the 'efficiency result'. Such information should make it easier for them to create an overview of all relevant concepts, supporting them in finding multiple solutions to the problem in the following phase.

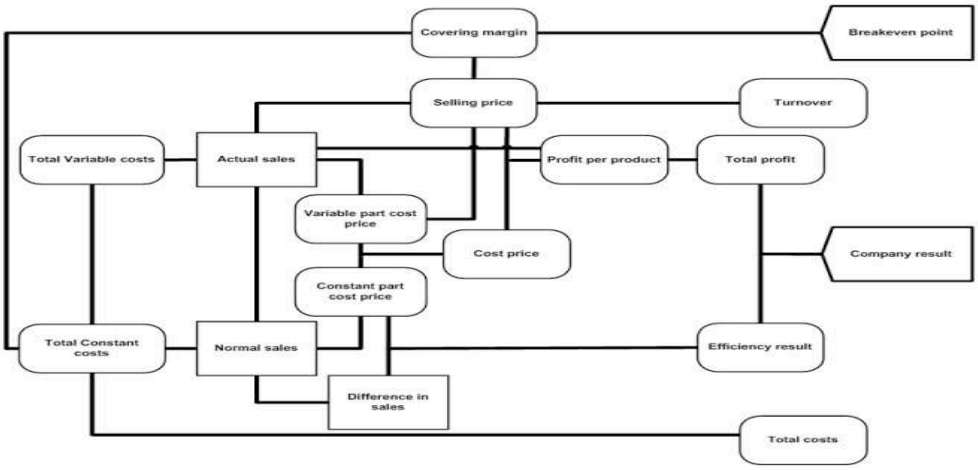

Figure 2. Conceptual ER.

The *problem solution* phase focused on creating a causal problem representation (i.e., making underlying business-economics principles explicit) by asking students to formulate several solutions to the problem. During this part-task, students received the causal ER (i.e., a static content scheme; see Figure 3), in which the causal relationships - visible through the arrows showing direction of the relationship between the concepts - were specified. The causal ER also contributed to increasing students' qualitative understanding by providing the students with possible interventions (i.e., changes in the business strategy), that each had a different effect on the company results. This should make it easier to effectively explore the solution space and should, in turn, support students in finding multiple solutions to the problem. Students could, for example, see that a PR-campaign affects 'actual sales that in turn affects 'total profit'.

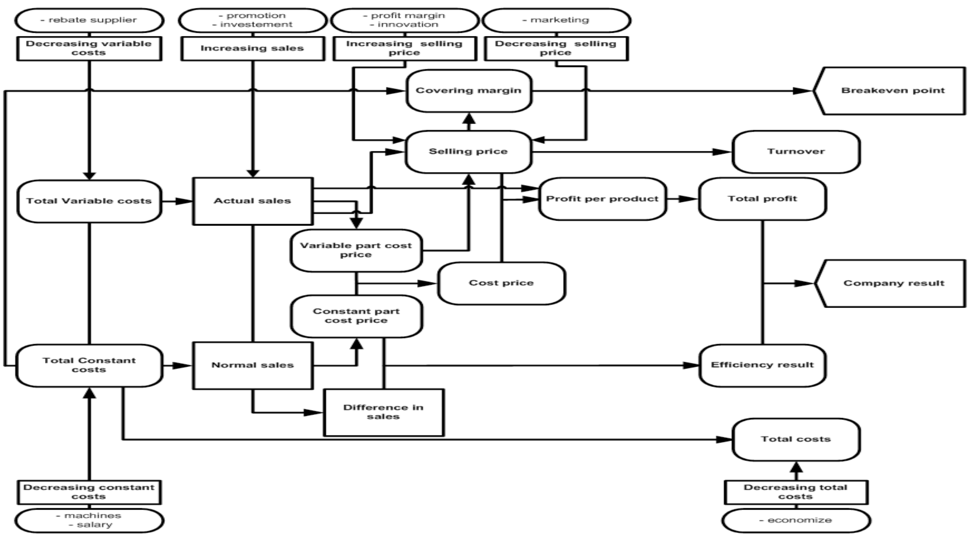

Figure 3. Causal ER.

Finally, the *solution evaluation phase* focused on increasing the students' understanding of the knowledge domain with the aid of a quantitative problem representation. Students were asked to determine the financial consequences of their proposed solutions and to formulate a final advice for the entrepreneur by negotiating the suitability of the different solutions with each other. During this phase, students received a simulation ER (i.e., a dynamic content scheme; see Figure 4) that enabled them to manipulate the values of the concepts by clicking on the arrows in the boxes. When the value of a certain concept was changed (i.e., increased or decreased), the simulation model automatically computed the values of all other concepts. This is meant to facilitate the determination and negotiation of the suitability of the different proposed solutions and reaching a final advice. Students could, for example, test how the PR-campaign affects the 'actual sales' and whether this in turn affects the 'total profit'. Only the simulation ER is capable of providing this kind of support, because the relationships between the concepts in this ER were specified as equations.

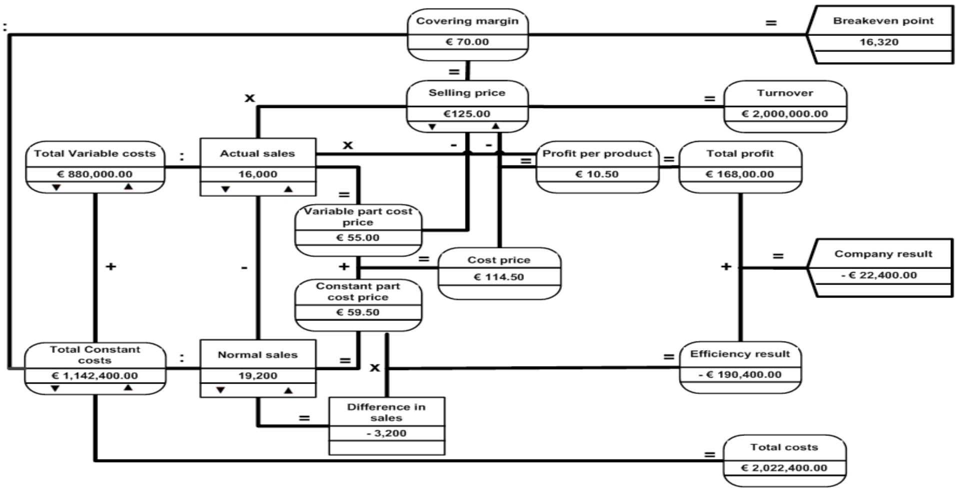

Figure 4. Simulation ER

Procedure

All groups spent three, 70-minute, lessons solving the problem during which each student worked on a separate computer in a computer classroom. Before the first lesson, students received an instruction about the CSCL-environment, the group composition, and the problem-solving task. Students worked on the problem in the computer classroom, where all actions and answers to the part-tasks were logged.

Measures

Problem-solving performance

To measure the effect of condition on problem-solving performance an assessment form for all criteria of the problem-solving task was developed (see Table 2). All 41 items were coded as; 0, 1 or 2, whereby a '2' was coded when the answer given was of high quality (e.g., more suitable). Groups could, thus, achieve a maximum score of 82 points (41 * 2 points).

Table 2: Problem solving performance; items and reliability

Criteria	Description	Items	α
Suitability	Whether the groups' answers were suited to the different part-tasks	9	.81
Elaboration	Number of different business-economics concepts or financial consequences incorporated in the answers to the different part-tasks	9	.56
Justification	Whether the groups justified their answers to the different part-tasks	9	.71
Correctness	Whether the groups used the business-economics concepts and their interrelationships correctly in their answers to the different part-tasks	9	.68
Continuity	Whether the groups made proper use of the answers from a prior problem phase	2	.67
Quality advice	Whether the groups gave a proper final advice - Number of business-economics concepts incorporated in the advice - Number of financial consequences incorporated in the advice - Whether the final answer conformed to the guidelines provided	3	.76
Total score	Overall score on the problem-solving performance	41	.92

Coordination processes

To examine the effect of condition data concerning students' coordination processes was collected by logging the chat-utterances of the group members. The content of these chat-protocols is assumed to represent what students know and consider important for carrying out their problem-solving task (Chi, 1997). A dialogue act is regarded as a communicative action that is elicited for a specific purpose representing a specific function in the dialogue (Erkens, et al., 2005), namely:

- argumentatives; indicating a line of reasoning,
- responsives; indicating responses to questions or proposals,
- informatives; indicating a transfer of information, often statements or evaluations,
- elicitatives; indicating questions or proposals requiring an answer,
- imperatives; indicating commands to take action or to draw attention.

Dialog-act coding was based on the occurrence of characteristic words or phrases (i.e., discourse markers) that indicated the communicative function of an utterance. The chat-protocols were searched for the occurrence of these discourse markers that led to the identification and coding of the dependent variables (see Table 2). This was automatically done with a MEPA-filter using 'if-then' decision rules that uses pattern matching to find typical words or phrases. Reliability of the dialogue act coding is 79% (Erkens & Janssen, 2008). After coding, score-frequencies for each dialogue act were computed and combined resulting in the measurement of the dependent variables.

Table 3: Coding of Students' Communicative Activities

Activities	Dialogue Act	Description	Example discourse marker
Focusing	Elicitative proposal for action	Proposition for action	Shall we get started with the first part-task?
	Elicitative question open	Open question with a lot of alternatives	What do you think we should do next?
	Imperative action	Command to perform an action	Write the conclusion
	Imperative focus	Command for attention	Look at the representational tool
	Elicitative question verify	Question that can only be answered with yes or no	Do you refer to the company result?
Checking	Elicitative question set	Question where the alternatives are already given (set)	Are you for / against increasing sales?
	Responsive confirm	Confirming answer	Yes, sure
	Responsive deny	Denying answer	No, not
	Responsive accept	Accepting answer	Oh, Yes
Argumentation	Argumentative reason	Reason	Because….
	Argumentative against	Objection	But …
	Argumentative conditional	Condition	If … (then …)
	Argumentative then	Consequence	Then …
	Argumentative disjunctive	Disjunctive	…or… or
	Argumentative conclusion	Conclusion	Thus…

Data analyses

In CSCL, group members influence each other (i.e., behave more or less similarly) causing non-independence of measurement (Kenny, Kashy, & Cook, 2006). This is problematic because many statistical techniques assume score independence and a violation compromises interpretation of the analyses (see Kenny, et al.). Non-independence was determined by computing the intraclass correlation coefficient and its significance (Kenny, et al.), for all dependent variables for student interaction. This resulted in non-independence ($\alpha < .05$) for all tests, justifying *Multilevel analysis* (MLA). MLA compares the deviance of an empty model and a model with one or more predictor variables to compute a possible decrease in deviance. The latter model is considered a better model when there is a significant decrease in deviance compared to the empty model (tested with a χ^2-test). All reported χ^2-values were significant ($\alpha < .05$) and, therefore, the estimated parameter of the predictor variables (i.e., effects of condition) were tested for significance. Due to the detection of outliers, the utterances of some students were deleted from the MLAs.

Results

Coordination processes

MLAs revealed that experimental condition significantly predicted the management of the interaction in the content space. The mean scores, standard deviations and the main effects (i.e., difference between match condition and non-matched conditions) for the communicative activities are listed in Table 4. A main effect for *coordination* was found, namely that students in the match condition, in total, exhibited more communicative activities compared to students in three non-matched conditions (β = 37.36, p = .01). For the specific communicative activities, the following results were obtained. First, a main effect was found for *focusing*; students in the match condition verified whether they were discussing the same topic and repaired the common focus more often than students in the non-matched conditions (β = 8.48, p = .01). When comparing the match condition to the other conditions separately, the effects were significant between all conditions. Second, a main effect for *checking* was found; students in the match condition devoted more attention to guarding the coherence and consistency of their shared understanding of the content space than students in the non-matched conditions (β = 16.37, p = .02). When comparing the match condition to the other conditions separately, this was the case for both the conceptual (β = 16.02, p = .00) and the simulation (β = 23.20, p = .00) conditions. Finally, a main effect was found for *argumentation*; students in the match condition exhibited more argumentative activities than students in the non-matched conditions (β = 12.19, p = .00). When comparing the match condition to the other conditions separately, this was the case for the causal (14.19, p = .03) and simulation (β = 15.84, p = .04) conditions.

As expected, students in the match condition were better able to establish and maintain shared understanding of the content space and negotiate about it better than students in the non-matched conditions. This enabled students in the match condition to acquire multiple perspectives on the problem and the problem-solving strategy, that are both seen as beneficial to problem-solving. Although more differences were expected, only one significant difference between the match and the causal condition was found.

Table 4: Multilevel Analyses concerning Students' Communicative Activities

	Conceptual condition (n = 10)	Causal condition (n = 10)	Simulation condition (n = 10)	Match condition (n = 6)	Effects match condition (N = 36)		
	M (SD)	*M (SD)*	*M (SD)*	*M (SD)*	$\chi^2(3)$	β	*SE*
Coordination	76.50 (37.58)	60.62 (44.41)	46.40 (17.33)	149.40 (39.33)	33.42	37.36*	11.57
Focusing	16.92 (10.97) -	12.38 (5.45) -	8.20 (4.94) -	33.40 (19.98) +	24.11	8.48*	3.06
Checking	40.42 (17.40) -	32.88 (32.54)	26.50 (9.08) -	72.60 (7.83) +	25.89	16.37*	6.94
Argumentation	19.17 (13.12)	15.38 (13.27) -	11.70 (7.39) -	43.40 (16.64) +	26.21	12.19**	3.49

Notes. * $p < .05$; ** $p < .01$; if match condition significantly > a mismatch condition than the match condition is indicated with a + and the mismatch condition with a -

Problem-solving performance

One-way MANOVA on the total score of the problem-solving performance showed that groups in the match condition indeed scored significantly higher than groups in both the conceptual (p = .02; d = 2.28) and the simulation condition (p = .05; d = 1.90). Groups receiving a congruent ER for each part-task gave answers that (1) were more suited for a specific part-task, (2) contained more business-economics concepts and financial consequences, and (3) were more often correct. Although expected, no significant differences were found between the match and the causal condition.

Discussion

Although based on 13 triads, the results of our study confirmed that providing part-task congruent guidance in the representational tools beneficially affects coordination processes and problem-solving performance. Groups receiving such support during their online collaborative problem-solving task were better able to coordinate their discussions about the concepts, principles and procedures of the knowledge domain than groups not receiving it. That is they more often (1) verified whether they are actually talking about the same discourse topic and, where necessary, repaired the common focus (i.e., focusing), (2) guarded the coherence and consistency of their shared understanding of the content space (i.e., checking), and (3) argued about their different points of view (i.e., argumentation). Those students were, therefore, better able to discus multiple perspectives on the problem and the problem-solving strategy (Hmelo-Silver, et al., 2007) and resulted in better answers to the part-tasks and better final solutions to the problem. Although the results seem very promising problem-solving performance of students in the causal condition was very similar to what was found in the match condition. Students in both conditions received the causal ER, that showed all relevant concepts, solutions and their causal interrelationships, providing the students multiple qualitative perspectives on the knowledge domain. It seems, therefore, important to support causal reasoning during collaborative problem-solving. Combining the causal ER with both other ERs might also hinder problem-solving when students experience difficulties integrating the different ERs. When students do not know how to combine multiple ERs, they might choose to stick with the familiar one and make no attempt to integrate the different ERs (Ainsworth, 2006). Additional research into the effects of representational scripting should be carried out to gain more insight into how students use and combine the concepts, solutions and relations within and between different ERs.

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