Constructing Part-task Congruent Representations to Support Coordination of Collaborative Problem-solving Tasks

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Abstract: This study investigated whether constructing part-task congruent domain-specific representations supports teams in establishing and maintaining a shared understanding of the knowledge domain and negotiating about it. This better coordination of team' 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 a predefined order, but differed in the representational tool(s) they received. In the matched condition, teams received the three tools in a part-task congruent manner. In the other three non-matched conditions, teams received one of the tools for all three part-tasks, thus a tool congruent to one part-task and incongruent for the other two. The results show that coordination processes were indeed better which might explain why teams in the matched condition performed better on the complex problem-solving task. However, similar results were obtained by teams who only received a tool for constructing causal representations for all part-tasks.

Introduction

There has been a recent surge in the interest of educational researchers for studying the effects of computer-supported tools for fostering team' complex learning-task performance (e.g., Slof, Erkens, Kirschner, Jaspers, & Janssen, 2010). Carrying out complex learning tasks, such as solving complex problems, often requires learners to actively engage in a dynamic process of sense-making by articulating and discussing multiple representations on the problem and their problem-solving strategy. Through externalizing one's knowledge, discussing this with peers, and establishing and refining the teams' shared understanding of the domain, learners may acquire new knowledge and skills and process them more deeply (e.g., Hmelo-Silver, Duncan, & Chinn, 2007). It, however, seems that such meaningful discussions about the domain can hardly be reached when learners are not aware of each others' knowledge, ideas and do not negotiate about them with their peers. In this respect, it is often advocated that 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 (e.g., Erkens & Janssen, 2008). Research on Computer Supported Collaborative Learning (CSCL) has shown that collaboratively constructing and discussing external representations can beneficially affect complex learning-task performance. Embedding representational tools in a CSCL-environment can facilitate learners' construction of different representations of the domain through its representational guidance and, thereby, guide their domain-specific interaction (Fischer, Bruhn, Gräsel, & Mandl, 2002; Suthers, 2006). Furthermore, in their discussions learners can refer to the constructed representation (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, often neglect the fact that problem-solving tasks are usually composed of fundamentally different phase-related part-tasks (1) problem-orientation (i.e., determining core concepts and relating them to the problem), (2) problem-solution (i.e., proposing solutions to the problem) and (3) solution-evaluation (i.e., determining suitability of the solutions and coming to a definitive solution to the problem). Important here is that each part-task mostly requires a different domain-specific representation and, thus, requires a tool with a different kind of representational guidance. When the design of the tool is incongruent with the demands of one or more part-tasks, learners may experience communication problems and problem-solving performance might decrease (e.g., Van Bruggen, Boshuizen, & Kirschner, 2003). The study presented in this paper is aimed at determining whether (1) proper coordination process can be evoked through constructing part-task congruent representations and (2) such an approach can lead to better problem-solving performance.

Coordination Processes

For meaningful discussion to arise, learners have to properly coordinate their discussions of the concepts, principles and procedures by carrying out communicative activities such as (1) making their own knowledge and ideas explicit to other group members, (2) focusing, (3) checking and (4) argumentation (Andriessen, Baker, & Suthers, 2003; Erkens & Janssen, 2008). When made explicit, learners have to try to maintain a shared topic of discourse and to repair a common focus if they notice a focus divergence. Learners coordinate their topic of discourse by *focusing*. Also, not all concepts, principles, and procedures are relevant for carrying out a part-task, thus, learners also have to guard the coherence and consistency of their shared understanding of the knowledge domain (e.g., Erkens & Janssen, 2008). By *checking*, learners 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 (e.g., Van der Linden, Erkens, Schmidt, & Renshaw, 2000). Furthermore, learners have to 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 (e.g., Kirschner, Beers, Boshuizen, & Gijselaers, 2008).

Constructing Part-task Congruent Representations

In the research reported on in this article, learners collaborated on solving a case-based business-economics problem in which they had to advise an entrepreneur about changing the business strategy to increase profits. Due to its different part-tasks, such a problem-solving task require multiple representational tools facilitating the construction of different representations. The specific ontology (i.e., objects, relations, rules for combining them) of each tool guides learner interaction in a specific manner by supporting them in using restricted views of the knowledge domain (i.e., problem representations). To effectively do this, one must carefully match the tools' ontology to the different part-task demands (Van Bruggen et al., 2003; Slof et al., 2010). Scripting was employed to ensure this alignment between tool, tool use and part-task demands. 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" (2002, 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 might be evoked.

Table 1: Congruence between representational tool and phase-related part-task demands.

Problem phase	Task demands	Representational tool	Representational guidance
Problem-orientation	Determining core concepts and relating them to the problem	Conceptual	Visualizing concepts and their conceptual relationships
Problem-solution	Proposing multiple solutions to the problem	Causal	Visualizing causal relationships between the concepts and the possible solutions
Solution-evaluation	Determining suitability of the solutions and coming to a definitive solution to the problem	Simulation	Visualizing mathematical relationships between the concepts and enabling manipulation of their values

In the *problem-orientation* phase learners have to explain what they think the problem is and describe what the most important factors are for solving it. The interaction should, therefore, be guided towards selecting the core concepts needed to carry out this part-task and discussing how those concepts are qualitatively related to each other. The design of the representational tool should facilitate learners in constructing and discussing a global qualitative problem representation by guiding and supporting them in conceptually relating the relevant concepts. Figure 1 shows an experts' representation of the concepts and their conceptual interrelationships involved in this study. The conceptual representational tool facilitates representation of the concepts and their interrelationships shown in Figure 1. Selecting and relating concepts that the learners may regard as beneficial for solving the problem supports them in becoming more familiar with those concepts and in broadening their problem space. Learners receiving the conceptual tool could, for example, make explicit that the 'company result' is related to the 'total profit' and 'efficiency result'. This should guide those learners in elaborating (i.e., causal, mathematical) on the relationships in the two following problem phases, making it easier for them to find multiple solutions to the problem and to evaluate their effects.

In the *problem-solution* phase learners have to formulate several changes of the business strategy (i.e., interventions) and make clear how they might solve the problem (i.e., problem-solution) by describing how they will affect the outcomes (i.e., company results). The interaction should, thus, be guided towards formulating multiple interventions and discussing how each of these interventions affects the selected core concepts by further specifying the relationships between the concepts and the proposed interventions. The representational tool should facilitate construction and discussion of a causal problem representation by causally relating concepts to each other and to possible interventions. Figure 2 shows an experts' representation of the concepts, the possible interventions and their causal interrelationships involved in this study. The causal representational tool facilitates representation of the concepts, interventions and their interrelationships shown in Figure 2. Selecting relevant concepts and interventions and causally relating them supports the effective exploration of the solution space and, thus, of finding multiple solutions to the problem. Learners receiving the causal representational tool could, for example, make explicit that an intervention such as a employing a promotion-campaign (e.g., placing an advertisement in a paper) affects 'actual sales', which in turn affects 'total profit'. Only conceptually representing the interrelationships of the concepts, as in the first problem phase, is not expressive enough for this part-task since the relationships need to be further specified and learners need additional information about the possible solutions. If this is not the case, then learners are forced to come up with a solution (i.e., the advice) themselves without sufficient understanding of the underlying qualitative principles governing the domain.

Finally, in the *solution-evaluation phase* learners have to determine the financial consequences of their proposed interventions and formulate a suitable and definitive advice for the entrepreneur by discussing the suitability of the different interventions with each other. The interaction should, therefore, be guided towards determining and comparing the financial consequences by discussing the mathematical relationships between the selected concepts. The representational tool must, thus, facilitate constructing and discussing a quantitative representation by specifying the relationships as equations. Figure 3 shows an experts' representation of the concepts and their mathematical interrelationships involved in this study. The simulation representational tool facilitates representation of the concepts and their interrelationships shown in Figure 3. Selecting relevant concepts and specifying the interrelationships as equations supports learners in evaluating the effects of their proposed interventions and, thus, in coming to a suitable advice. Learners receiving the simulation representational tool could, for example, simulate how an intervention such as employing a promotion-campaign affects the 'actual sales' and whether this affects the 'total profit'. By entering values and adjusting them (i.e., increasing or decreasing), the values of the other related concepts are automatically computed. Since such quantitative representations can only be properly understood and applied when learners have well-developed qualitative understanding of the domain, this kind of support is only appropriate for carrying out this type of part-task.

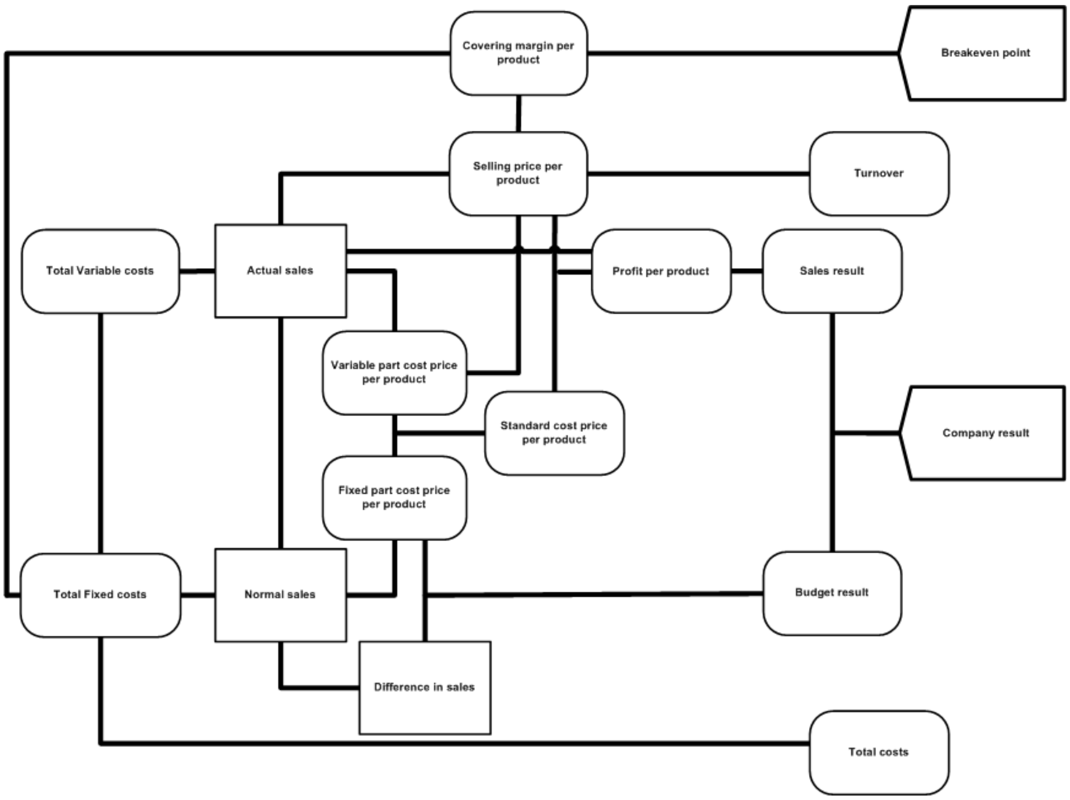

Figure 1. Experts' Conceptual Representation of the Domain.

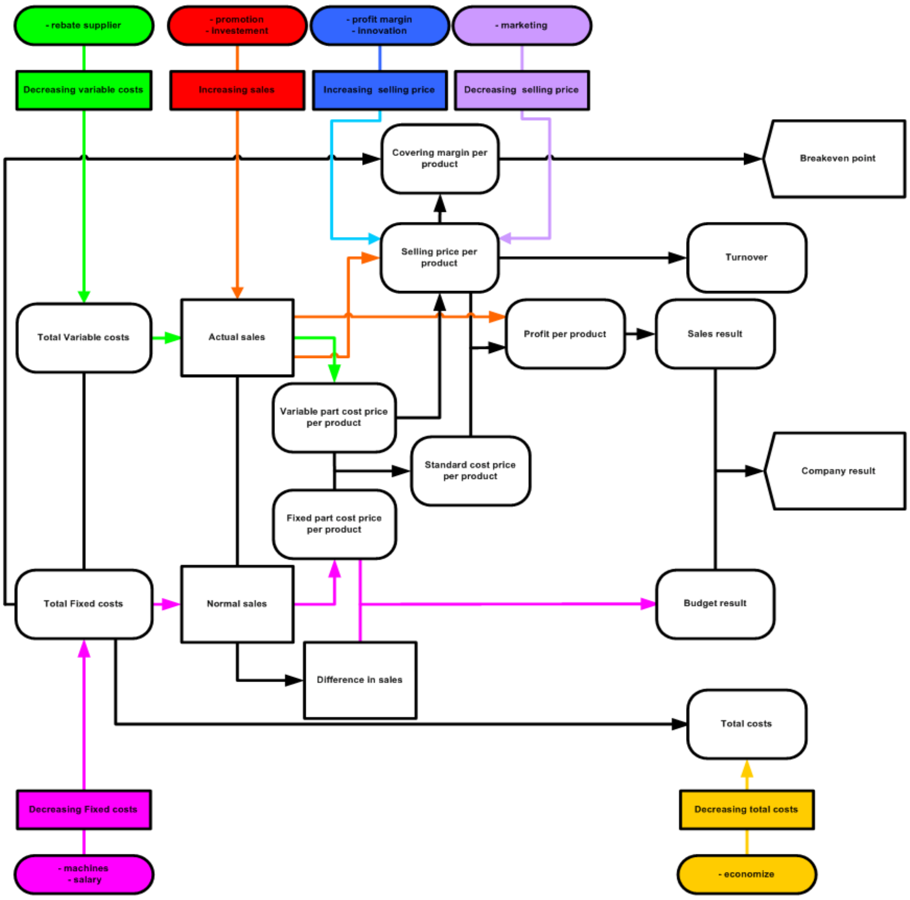

Figure 2. Experts' Causal Representation of the Domain.

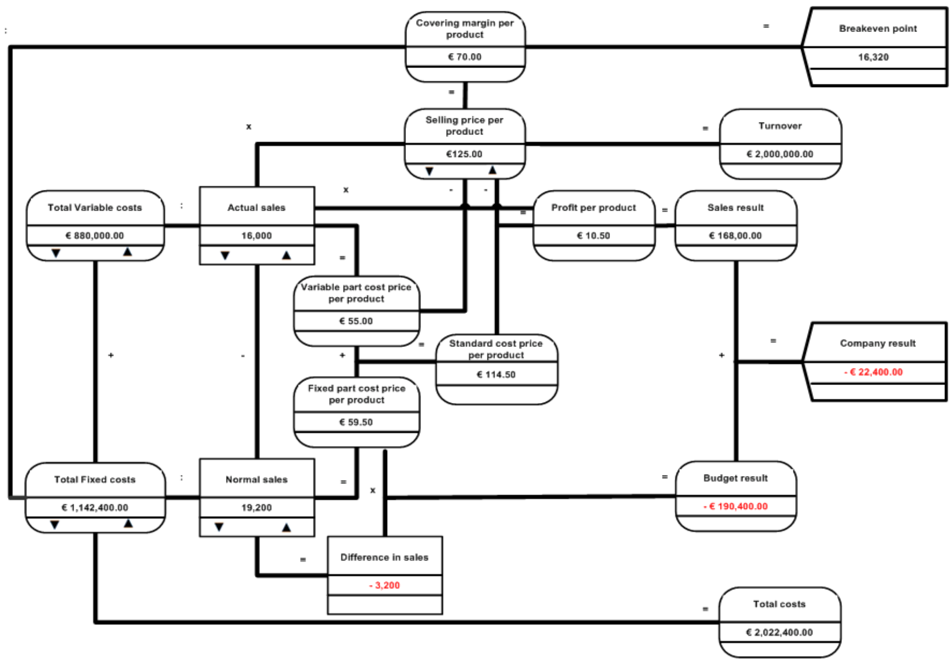

Figure 3. Experts' Mathematical Representation of the Domain.

Design and Expectations

The research reported on here was aimed at determining whether constructing part-task congruent representations affects both teams' 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 representational tool. To study the effect of condition, the tools' representational guidance was either matched or mismatched to the different problem phases; in other words it was either congruent or incongruent with the required task activities (see Table 2).

Table 2: Overview of the experimental conditions.

Problem phase	Condition and provided representational tool			
	Conceptual condition	Causal condition	Simulation condition	Matched condition
Problem-orientation	*Conceptual tool*	Causal tool	Simulation tool	*Conceptual tool*
Problem-solution	Conceptual tool	*Causal tool*	Simulation tool	*Causal tool*
Solution-evaluation	Conceptual tool	Causal tool	*Simulation tool*	*Simulation tool*

Teams in all conditions were scripted to carry out all the part-tasks in a predefined order, but differed in the representational tool(s) - conceptual, causal or simulation - they received. In the *matched condition*, teams received the three tools in a part-task congruent manner. In the other three *non-matched conditions*, teams received one of the tools for all three part-tasks, thus a tool congruent to one part-task and incongruent for the other two. Due to this presumed match between tools' representational guidance and the part-tasks, it was hypothesized that teams in the matched condition would *(H1)* experience a qualitatively better learning process, evidenced by carrying out more communicative activities to coordinate their collaborative problem-solving process and *(H2)* achieve a better problem-solving performance, evidenced by arriving at better interventions.

Method

Participants

Participants were students from six business-economics classes in three secondary education schools in the Netherlands. The total sample consisted of 93 learners (60 male, 33 female; mean age = 16.74 years; SD = .77, Min = 15, Max = 18). The students were, within classes, randomly assigned to a total of 31 teams of learners (i.e., triads); seven teams in the matched condition and eight teams in each of the three non-matched conditions.

Problem-solving Task and Materials

CSCL-environment: Virtual Collaborative Research Institute

Teams worked in a CSCL-environment called Virtual Collaborative Research Institute (VCRI, see Figure 4; Jaspers, Broeken, & Erkens, 2005).

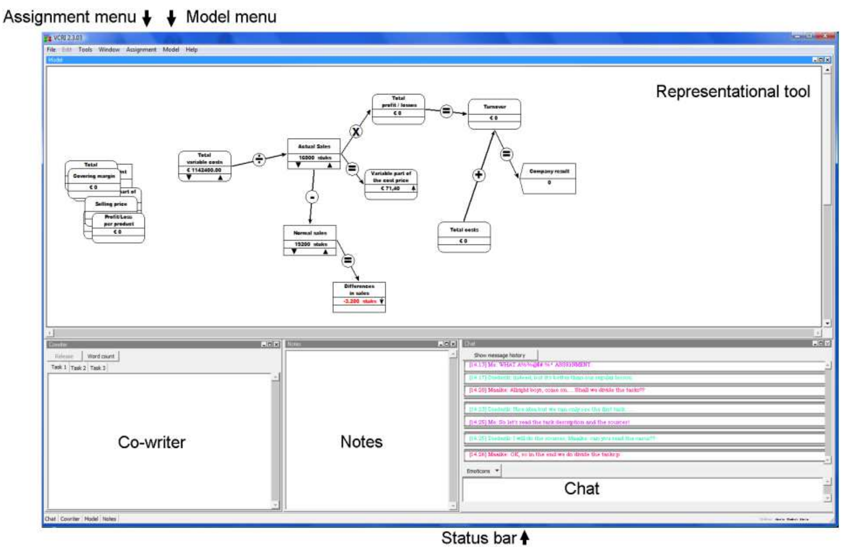

Figure 4. Screenshot of the VCRI-program; Simulation Representational Tool.

Problem-solving Task and Part-task Congruent Representations

All teams were coerced to carry out the part-tasks in a predefined order (i.e., used the same script) and could, thus, only start with a new part-task after finishing an earlier part-task. When team 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 learners, namely they were instructed to (1) carry out a new part-task and (2) revise their representation of the domain so it concurred with the decisions they gave to the new part-task. Learners in the non-matched conditions were facilitated in elaborating on their previously constructed representation. Since those learners kept the same representational tool, all concepts and their relationships remained visible and could be revised as learners seemed appropriate for carrying out their new part-task. Learners in the matched condition were facilitated in using a different qualitative or quantitative perspective of the domain. That is, the previously selected concepts remained visible and learners were instructed to replace the relationships by specifying them in a causal manner or as equations with the aid of their new representational tool.

Procedure

All teams spent six, 45-minute, lessons solving the problem during which each team member worked on a separate computer. Before the first lesson, learners received an instruction about the CSCL-environment, the complex learning task, and the team composition. students worked on the problem in the computer classroom where all actions and decisions were logged.

Measures

Coordination Processes

To examine the effect of condition data concerning learners' coordination processes was collected by logging the chat-utterances of the group members. A dialogue act is regarded as a communicative action that is elicited for a specific purpose representing a specific function in the dialogue (Erkens & Janssen, 2008). 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 4). 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 filter compared to hand-coding is 79% (Erkens & Janssen, 2008). After coding, score-frequencies for each dialogue act were computed and combined resulting in the dependent variables.

Table 3: Coding of learners' 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…

Problem-solving Performance

To measure the effect of condition on problem-solving performance an assessment form for criteria of the problem-solving task, such as correctness, elaborateness and suitability of the decisions to all part-tasks, was developed. All 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).

Data Analyses

In CSCL, team 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. Non-independence was determined by computing the intraclass correlation coefficient and its significance (Kenny, et al., 2006), 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).

Results

Coordination Processes

MLAs revealed that condition was a (marginally) significant predictor for the communicative activities learners exhibited when comparing learners in the matched condition to those in both the conceptual ($\beta = 23.84$, $p = .06$) and the simulation conditions ($\beta = 42.00$, $p = .00$). When analyzing learners' communicative activities for the conditions separately, several category effects were found (see Table 4). First, a significant category effect for *focusing* was found; learners in the matched condition were better able to coordinate what their topic of discourse was than learners in both the conceptual ($\beta = 4.22$, $p = .05$) and the simulation conditions ($\beta = 6.68$, $p = .02$). Second, a significant category effect for *checking* was found; learners in the matched condition devoted more attention to guarding the coherence and consistency of their shared understanding of the domain than learners in both the conceptual ($\beta = 14.08$, $p = .04$) and the simulation conditions ($\beta = 23.03$, $p = .00$). Finally, a significant category effect was found for *argumentation*; learners in the matched condition exhibited more argumentative activities than learners in the simulation condition ($\beta = 12.17$, $p = .02$). As expected, learners in the matched condition were better able to establish and maintain shared understanding of the domain than learners in both the conceptual and simulation conditions. These differences were, however, not obtained for the comparison with learners in the causal condition.

Table 4: Multilevel analyses for effects of condition concerning communicative activities.

	Conceptual condition ($n_{learner} = 24$)	Causal condition ($n_{learner} = 24$)	Simulation condition ($n_{learner} = 24$)	Matched condition ($n_{learner} = 21$)	Effects matched condition ($N_{learner} = 93$)		
	M (SD)	*M (SD)*	*M (SD)*	*M (SD)*	$\chi^2(3)$	β	*SE*
Coordination *	124.33 (59.01)	173.82 (130.42)	87.65 (54.21) -	170.36 (79.22) +	30.06	24.02	19.40
Focusing *	22.87 (8.20) -	31.50 (23.37)	18.13 (12.28) -	31.09 (15.83) +	18.42	4.30	3.52
Checking *	57.33 (31.43) -	88.95 (69.43)	39.17 (26.471) -	84.14 (38.56) +	27.74	14.22	9.84
Argumentation *	44.12 (26.92)	53.36 (43.65)	30.35 (19.95) -	55.14 (32.18) +	20.90	5.41	6.61

Note. * $p < .05$, ** $p < .01$; if matched condition significantly > a non-matched condition than the matched condition is indicated with a + and the non-matched condition with a -.

Problem-solving Performance

A one-way MANOVA on the total score for teams' problem-solving performance showed a significant difference for condition ($F(3,27) = 4.38$, $p = .01$). Bonferroni post hoc analyses revealed that teams in the matched condition scored significantly higher than teams of learners in both the conceptual ($p = .01$; $d = 1.46$) and the simulation conditions ($p = .01$; $d = 1.48$). When the results for the dependent variables were considered separately - using one-way ANOVAs with Bonferroni post hoc analyses - condition effects were found for 'justification' ($F(3,27) = 4.85$, $p = .01$) and 'correctness' ($F(3,27) = 3.97$, $p = .01$). First, teams in the matched condition provided more arguments for the decisions to the part-tasks (i.e., justification) than teams in both the conceptual ($p = .01$; $d = 1.56$) and simulation conditions ($p = .01$; $d = 1.56$). Second, teams in the matched condition used the business-economics concepts and their interrelationships more correctly in their decisions to the different part-tasks (i.e., correctness) than teams in both the conceptual ($p = .01$; $d = 3.97$) and simulation conditions ($p = .03$; $d = 2.52$). As expected, teams of learners receiving part-task congruent representational tools scored higher on problem-solving performance. Although expected, no significant differences were obtained between teams in the matched condition and the causal condition.

Discussion

The results indicate that teams of learners that received the complete array of tools (i.e., matched condition) were indeed fostered in their problem-solving performance. That is, those teams formulated better decisions with respect to the part-tasks and came up with better definitive solutions to the problem than learners in both the conceptual and the simulation conditions. This might be explained by the fact that learners in the matched condition exhibited more communicative activities than those in both the conceptual and simulation conditions. That is, they were better able to establish and maintain a shared understanding of the domain, which is regarded as a prerequisite for having a meaningful discussion of the domain (e.g., Van der Linden et al., 2000). It seems that the deictic power of the representational tool hindered learners in establishing and maintaining shared understanding of the domain (Suthers et al., 2003). In other words, when learners are unable to specify (i.e., conceptual tool) or being forced to explicitly specify (i.e., simulation tool) the relationship between concepts this hinders learners in properly referring to and relating their contributions in CSCL-environments. Although the results seem very promising, problem-solving performance of teams in the causal condition was very similar to what was found in the matched condition. Since teams in both conditions received the causal representational tool they were both facilitated in constructing and discussing a causal domain representation. Supporting learners' causal reasoning seems, thus, important for problem-solving. This result raises questions about whether constructing and applying multiple representations of a domain is beneficial for problem-solving performance. Additional research seems, therefore, needed to investigate whether learners:

- require qualitative as well as quantitative representations during their complex learning-task performance,
- combine qualitative and quantitative representations during their complex learning-task performance.

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