Representational Scripting to Support Students' Online Problem-solving Performance

Abstract: This study investigated the effects of representational scripting on student learning while online collaboratively solving a complex problem. The premise here is that effective student interaction would be evoked when the problem-solving task is structured into part-tasks that are supported by providing part-task congruent representations (i.e., representational scripting). It was hypothesized that such an approach would lead to a more appropriate student interaction and as a consequence better problem-solving performance. In triads secondary education students worked on a case-based business-economics problem in four experimental conditions, namely one condition in which the groups received representations that were congruent for all three part-tasks and three conditions in which the groups received one of these representations for all three part-tasks. The results show that using representational scripting indeed leads to a more elaborated discussion about the content of the knowledge domain (i.e., concepts, solutions and relations) and to better problem-solving performance.

Introduction

Collaboratively solving complex problems is often regarded as an effective pedagogical method that is beneficial for both group and individual learning. The premise underlying this approach is that through a dynamic process of eliciting one's own understanding of the content of the knowledge domain (i.e., concepts, principles and procedures) and discussing this with peers, students acquire new knowledge and skills and process them more deeply (e.g., Hmelo-Silver, Duncan, & Chinn, 2007). Unfortunately, putting students in groups and having them work together on a problem is not always beneficial for learning (e.g., Barron, 2003). Research on Computer Supported Collaborative Learning (CSCL) has shown that proper use of representational tools can beneficially affect externalizing, sharing and negotiating about the concepts, principles and procedures of the domain (e.g., Fisher, Bruhn, Gräsel, & Mandl, 2002). However, whereas these studies show promising results, other research questions how representational tools can best guide student interaction that is beneficial for learning (e.g., Suthers, 2006). Important here is that problem-solving tasks are usually composed of fundamentally different part-tasks, that each require the support of a different representational tool. Important here is that the guidance the tools are intended to provide is matched to the demands of the different part-tasks. Otherwise this will hinder learning (e.g., Van Bruggen, Boshuizen, & Kirschner, 2003). Recently, *scripting* has been advanced as a way to ensure the alignment between tool, tool use and learning goals in collaborative learning (e.g., Weinberger, Ertl, Fischer, & Mandl, 2005). Scripting the problem-solving process with representation tools sequences the problem-solving process and makes the different part-task demands explicit so that they can be foreseen with task-congruent content-related guidance by the representational tools. By doing so, part-task related activities beneficial for collaborative problem-solving can be evoked.

Collaboratively Solving a Complex Problem

Collaboratively solving a complex problem is regarded to be a sequenced, phased process (i.e., problem orientation, problem solution, solution evaluation) where students actively engage in a process of sense-making in a knowledge domain, articulating and discussing multiple problem perspectives and problem-solving strategies (Ploetzner, Fehse, Kneser, & Spada, 1999; Van Bruggen, et al., 2003). Coping with the task demands of the different problem phases (i.e., part-tasks), requires students to interact in the *content space*; carry out part-task related activities such as discussing the concepts, principles, and procedures of the domain (Barron, 2003; Jonassen & Ionas, 2008). However, where expert problem-solvers experience no difficulties in carrying out these kinds of activities, students (i.e., non-experts) do. When solving problems, students rely primarily on surface features such as using objects referred to in the problem instead of the underlying principles of the knowledge domain, and employ weak problem-solving strategies such as working via a means-ends strategy towards a solution (Chi, 1997). Important here is that students lack a well developed understanding of the knowledge domain and as a consequence have problems creating and combining meaningful problem representations. This hinders students in effectively and efficiently carrying out their problem-solving task because the ease with which a problem can be solved often depends on the quality of the available problem representations (Chi; Jonassen & Ionas). To this end, it would be beneficial if suitable representations were provided and combined in a part-task appropriate manner.

Representational Scripting

Integrating scripting with the availability of representational tools (i.e., representational scripting) structures the problem-solving process making it more efficient and effective. Scripting shapes the use of the representational tools and therefore also the epistemic and social processes of collaboration (Weinberger, et al., 2005) by sequencing and making the different part-task demands explicit so that they can be foreseen with task-congruent content-related guidance by the representational tools. Different representation tools provide different domain-specific content schemes (i.e., problem representation) representing different problem perspectives. Visualizing the knowledge domain through multiple external representations (ERs) influences student interaction by providing representational guidance (Suthers, 2006). The specific ontology (i.e., objects, relations, rules for combining them) of each ER offers a restricted view of the knowledge domain, guiding student interaction in a specific manner. Matching this representational guidance with the student interaction required to carry out a part-task evokes appropriate student interaction, leading to better problem-solving performance (see Table 1). To effectively do this, one must avoid or neutralize the difficulties encountered when combining multiple ERs, namely: translating from and coordinating between different ERs (Ainsworth, 2006), and incongruence between an ER and required part-task related activities (Van Bruggen, et al., 2003). This means that the representational guidance of the ER must be congruent (i.e., ontologically matched) to the part-task demands and activities of a specific problem phase. In this paper, the focus will be on guiding student interaction' when collaboratively solving a complex business economics problem.

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 between the concepts and enabling manipulation of their value

This study focuses on how the use of representational scripting affects both student part-task related interaction 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 effects of representational scripting, ERs were either matched or mismatched to the different problem phases; in other words they were either ontologically congruent or incongruent to the required part-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 ontologically 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 an ontological match between all three ERs and all three part-tasks. Due to the presumed match between ERs and part-tasks, student understanding and part-task related 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 part-task related activities and *(H2)* have better problem-solving performance.

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 tools that are part of the VCRI were augmented with representational scripting. All tools, except the Notes tool, were shared among group members.

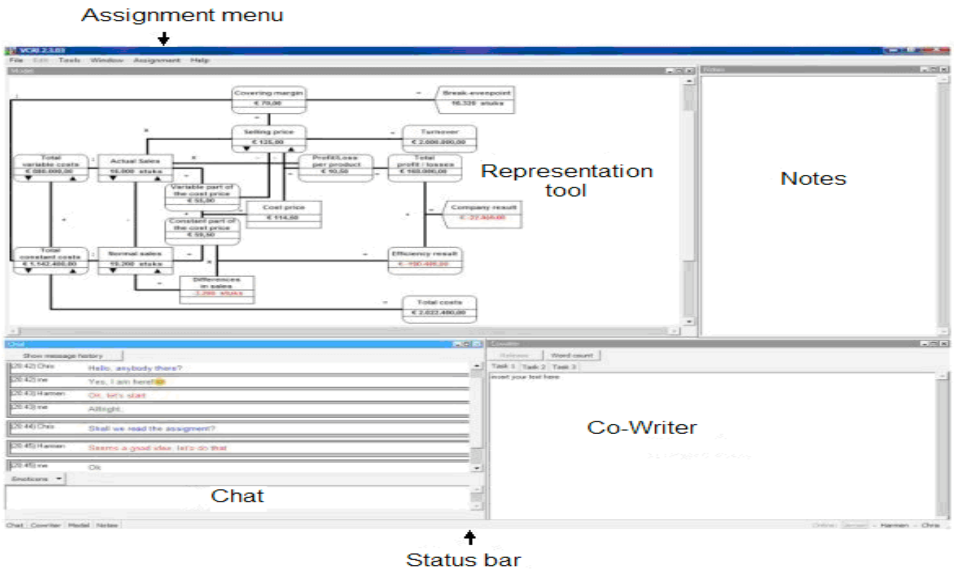

Figure 1. Screenshot of the VCRI-program.

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. All 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 design representational scripting

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 all 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.

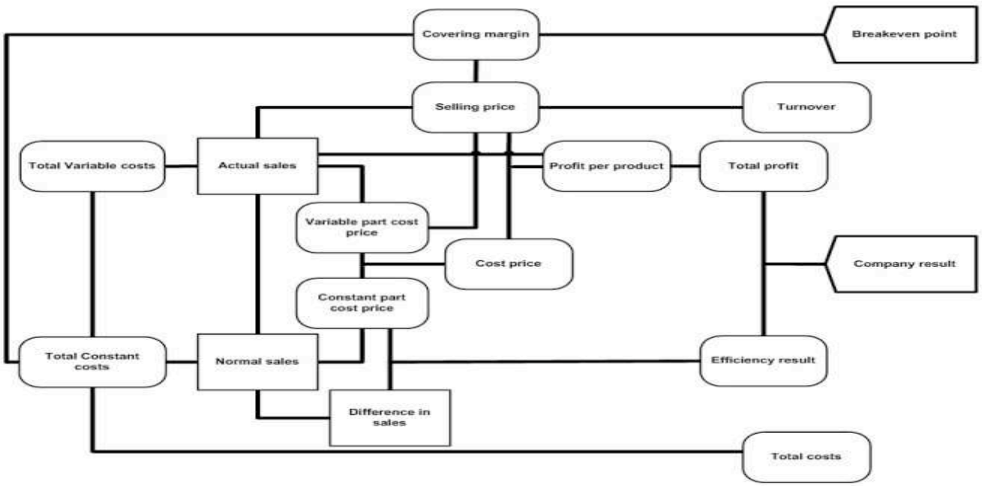

Figure 2. Conceptual ER.

The *problem solution* phase focused on creating a causal problem representation (i.e., explicating the underlying business-economics principles) by asking students to formulate several solutions to the problem. During this phase, 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), each of which 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’.

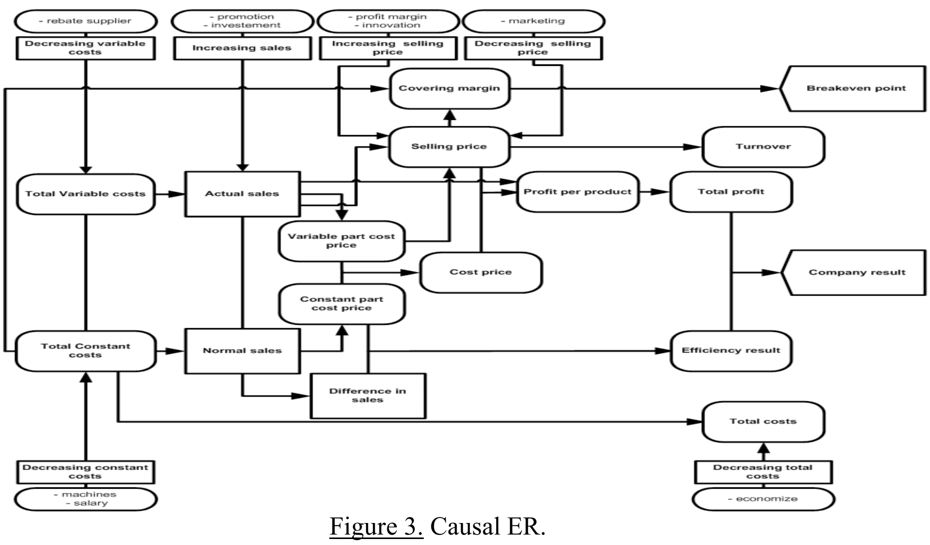

Figure 3. Causal ER.

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.

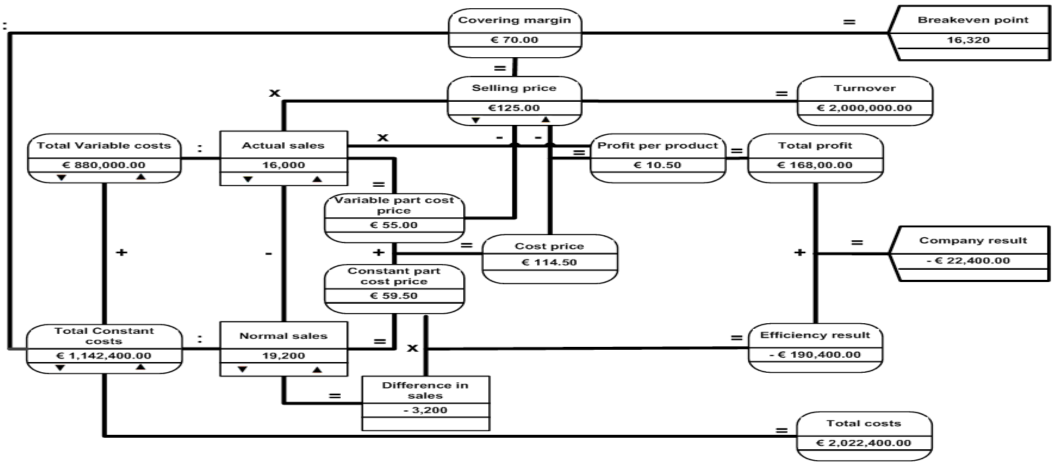

Figure 4. Simulation ER

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. The instruction made it clear that their group answer to the problem (i.e., problem-solving performance) would serve as a grade affecting their GPA. Students worked on the problem in the computer classroom, where all actions and answers to the part-tasks were logged.

Measures

Content-related student interaction

To examine the effect of condition data concerning student interaction 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). Using so called 'concordancers' software (e.g., MEPA, see Erkens & Jansen, 2008) minimizes the work associated with coding chat-protocols and maximizes coding reliability allowing the content of chat-protocols to be searched for the occurrence of characteristic words (i.e., key words) that led to the identification and coding of the dependent variables. This was done automatically with a MEPA-filter using 'if-then' decision rules containing different explicit references to a concept, solution or relation (e.g., name, synonyms) that were coded as representing that concept, solution or relation (see Table 2).

Table 2: Concepts, solutions and relations; coding and reliability MEPA-filter

Categories	Subcategories	Discussion of	Reliability
Concepts	Sales	how many products are sold / have to produced	90%
	Selling price	what the customer has to pay for the product	
	Costs	what the overall costs of the company are	
	Turnover	what the total income of the company is	
	Company result	whether it is profitable to run the company	
Solutions	Changing costs	how the overall costs can be decreased	84%
	Changing turnover	how the turnover can be increased	
	Changing both	the combining of the other two solutions	
Relations	Conceptual	the definition / meaning of a concept / solution	80%
	Causal	the causal relationship within / between concepts / solutions	
	Mathematical	the quantitative relationships within / between concepts	

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 3). The 41 items were coded as; 0, 1 or 2, whereby a '2' was coded when the answer given was of high quality. All groups could, thus, achieve a maximum score of 82 points (41 * 2 points).

Table 3: 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

Data analyses

When conducting studies on CSCL, group members mutually influence each other (i.e., behave more or less in the same way) leading to non-independence of measurement (Kenny, Kashy, & Cook, 2006). This is problematic because many statistical techniques (e.g., *t*-test) assume score independence and such a violation compromises the interpretation of the analyses (e.g., *t*-value, standard error, see Kenny, et al.). The non-independence was determined here by computing the intraclass correlation coefficient and its significance (Kenny, et al.), for all dependent variables concerning student interaction. This resulted in non-independence ($\alpha < .05$) for all tests, justifying *Multilevel analysis* (MLA) for analyzing these data. MLA entails comparing 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 in comparison 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. One-way MANOVA was used for answering the second research question. Since there were specific directions of the results expected (see hypotheses) all analyses are one-sided.

Results

Concepts, solutions and relations

MLAs revealed that experimental condition was a significant predictor for the number and kinds of concepts, solutions and relations that students discussed (see Table 4). The results show a main effect for *concepts*, students in the match condition discussed significantly more concepts in comparison to students in three non-matched conditions ($\beta = 9.08$, $p = .00$). When comparing the match condition to the other conditions separately, it appeared that students in the conceptual condition discussed concepts as 'sales' ($\beta = 2.03$, $p = .03$), 'turnover' ($\beta = 1.80$, $p = .00$) and 'company result' ($\beta = 2.55$, $p = .02$) less frequently than students in the match condition. The same kind of results were obtained when comparing students in the match condition to students in the simulation condition; 'sales' ($\beta = 2.00$, $p = .03$), 'turnover' ($\beta = 2.28$, $p = .00$) and 'company result' ($\beta = 3.19$, $p = .02$). Second, a main effect for *solutions* was found. Students in the match condition discussed significantly more solutions in comparison to students in the non-matched conditions ($\beta = 6.33$, $p = .00$). When comparing the match condition to the other conditions for the different kinds of solutions, students in the match condition discussed the solution aimed at increasing the company's turnover more often than students in the non-matched conditions ($\beta = 3.42$, $p = .03$). This effect was also significant between all conditions. Finally, Table 4 shows a main effect for *relationships*, students in the match condition discussed significantly more and different kinds of relationships than students in the non-matched conditions ($\beta = 11.68$, $p = .00$). When comparing the match condition to the other conditions separately, it appeared that (1) students in the conceptual ($\beta = 2.85$, $p = .03$) and the simulation condition ($\beta = 3.67$, $p = .02$) discussed significantly fewer conceptual relationships, (2) students in the conceptual condition discussed significantly fewer causal relationships (β = 6.41, p = .01), and (3), students in the conceptual (β = 2.50, p = .01) and the simulation (β = 2.68, p = .00) condition discussed fewer mathematical relationships.

Table 4: Multilevel Analyses for Effects concerning Students' Discussion of Concepts, Solutions and Relations

	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*
Concepts	8.36 (5.20)	10.88 (8.64)	4.50 (4.70)	26.50 (14.57)	25.37	9.08^{**}	2.00
Sales	1.09 (1.30) -	2.00 (2.14)	1.20 (1.14) -	5.17 (6.40) +	11.53	2.03^{**}	0.72
Selling price	0.27 (0.65)	1.00 (1.85)	0.20 (0.63)	2.33 (2.50)	5.67	1.03	0.54
Costs	3.18 (3.09)	3.50 (2.88)	1.50 (2.17)	6.50 (3.27)	13.18	1.67	0.70
Turnover	1.09 (1.45) -	1.25 (1.39)	0.10 (0.36) -	4.67 (3.08) +	16.51	1.79^{*}	0.40
Company result	2.73 (2.15) -	3.12 (3.14)	1.50 (1.78) -	7.83 (3.66) +	14.06	2.55^{*}	0.81
Solutions	6.00 (4.65)	7.12 (5.69)	2.80 (3.19)	18.67 (7.74)	23.29	6.33^{**}	1.45
Changing costs	3.09 (3.53)	3.75 (3.50)	1.50 (2.12)	6.33 (3.56)	10.87	1.62^{*}	0.81
Changing turnover	2.18 (1.94) -	2.88 (2.75) -	0.90 (1.11) -	10.33 (4.89) +	23.22	4.08^{**}	0.70
Changing both	0.73 (1.27)	0.50 (0.75)	0.40 (0.52)	2.00 (1.79)	3.88	0.64^{*}	0.32
Relations	11.73 (5.31)	18.37 (12.36)	8.10 (3.81)	35.17 (15.38)	39.48	11.68^{**}	2.98
Conceptual	4.00 (2.97) -	4.00 (5.16)	2.30 (2.50) -	9.67 (5.24) +	13.71	2.86^{*}	1.25
Causal	6.91 (3.89) -	2.38 (9.15)	5.30 (3.40)	19.67 (5.24) +	19.76	6.29^{*}	1.93
Mathematical	0.82 (1.33) -	2.00 (3.07)	0.50 (0.85) -	5.83 (5.42) +	15.39	2.51^{*}	0.68

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 a significant difference for condition (F(3, 9) = 1.99, p = .04; Pillai's Trace = 2.00; partial *eta* squared = .67). Bonferroni post hoc analyses 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). Table 5 shows the mean scores and standard deviations of the scores on the problem-solving performance. When the results for the dependent variables were considered separately, using one-way ANOVAs with Bonferroni post hoc analyses, condition effects were found for 'suitability' (F(3, 9) = 4.49, p = .02), 'elaboration' (F(3, 9) = 3.13, p = .04) and 'correctness' (F(3, 9) = 4.25, p = .02). The mean scores indicate that there were several significant differences between conditions. First, groups in the match condition scored significantly higher on 'suitability' than groups in both the conceptual condition (p = .03; d = 3.61) and the simulation condition (p = .05; d = 3.28). Second, groups in the match condition scored significantly higher on 'elaboration' than groups in the conceptual condition (p = .04; d = 1.57).

Table 5: One-way Multivariate Analysis concerning Group Problem-solving Performance

Criteria	Condition			
	Conceptual condition (n = 4)	Causal condition (n = 3)	Simulation condition (n = 3)	Match condition (n = 3)
	M (SD)	*M (SD)*	*M (SD)*	*M (SD)*
Suitability*	10.75 (1.50) -	13.67 (1.52)	11.33 (4.16) -	17.00 (1.73) +
Elaboration*	3.75 (2.06) -	6.67 (2.08)	6.00 (2.00)	9.67 (3.78) +
Justification	3.25 (2.06)	4.67 (3.06)	3.00 (3.00)	8.00 (4.00)
Correctness*	4.50 (1.29) -	6.33 (3.77)	5.33 (0.58) -	10.67 (2.89) +
Continuity	2.00 (1.41)	2.00 (1.00)	2.00 (1.73)	3.67 (0.58)
Quality advice	2.50 (0.58)	3.67 (0.58)	3.33 (2.52)	3.33 (1.53)
Total score*	26.75 (4.17) -	37.00 (7.00)	31.00 (12.00) -	52.33 (11.24) +

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 -

Discussion

As is the case with many other researchers, the present study stresses the importance of using representational tools (Fischer, et al., 2002) and of employing scripting (Weinberger, et al., 2005) to guide student interaction and problem-solving performance. However, instead of using them separately, this study combined the advantages of using multiple representations and scripting (i.e., representational scripting). The representational scripting structured the problem-solving process by sequencing and making the part-tasks explicit so that they could be foreseen with ontologically congruent content-related guidance in the representational tools. It was hypothesized that this would evoke more suited part-task related student interaction and, as a consequence, better problem-solving performance than not receiving it. Although based on 13 triads, the results of our study confirmed that the problem-solving process for these groups was more efficient and effective. Specifically, groups in the match condition had more elaborated discussions of the content of the knowledge domain, gave better answers to the part-tasks and a came up with better final solutions to the problem than groups in the non-matched conditions. Although the results seem very promising student interaction and 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. Providing ERs that foster causal reasoning seems, therefore, beneficial for collaborative problem-solving (Jonassen & Ionas, 2008). 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). Future research should be aimed at determining whether the results can be generalized to the same and other kinds of problem-solving tasks. Its seems also interesting to study the effects of the collaborative construction of external representations. Such an approach might lead to more insight into how students use and combine the concepts, solutions and relations within and between different ERs.

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