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Differences in learning processes between successful and less successful students in computer-supported collaborative learning in the field of human nutrition and health

Omid Noroozi [a,*], Harm J.A. Biemans [a], Maria C. Busstra [b], Martin Mulder [a], Mohammad Chizari [c]

[a] Chair Group of Education and Competence Studies, Wageningen University, The Netherlands
[b] Division of Human Nutrition, Wageningen University, The Netherlands
[c] Agricultural Extension and Education Department, Tarbiat Modares University, Tehran, Iran

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ABSTRACT

This study aimed to investigate the differences in learning processes between successful and less successful pairs of students in computer-supported collaborative learning (CSCL) in the field of human nutrition and health. As part of their regular MSc (and optional BSc) course "Exposure assessment in nutrition and health research" at Wageningen University, 44 students were asked (as an individual pretest) to design and analyze a study which evaluates a certain dietary assessment method. Subsequently, they were asked to discuss their evaluation studies in randomized pairs using a CSCL platform. As an individual posttest, students had to re-design and re-analyze the same evaluation study. The quality of students' knowledge construction in both tests and characteristics of their learning processes in the CSCL environment were assessed through two coding schemes. Based on their learning outcomes (quality of knowledge construction), pairs of students were divided into two subgroups: successful and less successful students. Next, the learning processes of these subgroups were compared. This study revealed that the learning processes of successful and less successful students in the CSCL environment differed in terms of relevance, width and depth of discussion and justification and reasoning. Based on these findings, recommendations for further research and educational practice are formulated.

1. Introduction

In computer-supported collaborative learning (CSCL), learners are encouraged to discuss ideas, concepts and problems from different perspectives and viewpoints (Van Bruggen, 2003) in order to re-construct and co-construct (new) knowledge (Mahdizadeh, Biemans, & Mulder, 2008; Veldhuis-Diermanse, Biemans, Mulder, & Mahdizadeh, 2006). CSCL provides an educational environment that prepares students to cope with authentic problems and issues (Jacobson & Wilensky, 2006) and also facilitates and supports students' learning processes and outcomes (Claudia, Steil, & Todesco, 2004; Ellis & Calvo, 2004; Hung, Tan, & Chen, 2005; Wang & Woo, 2007).

Students' learning processes and outcomes in CSCL environments have been subjects of interest to many researchers (see e.g. Mcdonald, 2003; Veldhuis-Diermanse et al., 2006). However, in many cases, learning processes and outcomes of CSCL have been studied separately, even though many authors have argued that differences in learning outcomes are related to differences in learning processes and activities (e.g. Koschmann, 1996; Reimann, 2007; Russell, 1999). Therefore, it is important to study learning processes in relation to learning outcomes to reveal the connectivity between the two (Andriessen, Baker, & Suthers, 2003; Joiner & Jones, 2003; Weinberger & Fischer, 2006). This implies that to truly understand the learning that takes place in CSCL environments, research on CSCL should be both process-focused and result-focused (Koschmann, 1996; Mcdonald, 2003; Palincsar & Brown, 1989; Stegmann, Weinberger, & Fischer, 2007; Veerman, 2000, 2003; Veldhuis-Diermanse, 2002).

Many aspects of learning processes and activities in CSCL have been studied in the past decade. For example, Veldhuis-Diermanse (2002) focused on the cognitive, affective, and metacognitive learning activities in CSCL environments. Baker, Andriessen, Lund, Van Amelsvoort, and Quignard (2007) and Van Amelsvoort, Andriessen, and Kanselaar (2007) investigated students' learning processes and activities in terms of outside activity, social relations, interaction management, task management, opinions, arguments, exploration and deepening of discussions. Their work showed that students engage not only in discussions and arguments in CSCL

* Corresponding author. Address: Chair Group of Education and Competence Studies – Bode 68, Wageningen University, P.O. Box 8130, NL-6700 EW Wageningen, The Netherlands. Tel.: +31 317 48 27 10; fax: +31 317 48 45 73.
E-mail addresses: omid.noroozi@wur.nl, omid_noruzi@yahoo.com (O. Noroozi).

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environments, but also in off-task activities as well as social interaction and management activities. Weinberger and Fischer (2006) mentioned that in order to construct knowledge in CSCL, students engage in four independent dimensions of collaborative learning: participation, epistemic, argumentative and socio-modes of co-construction. In addition, Mcdonald (2003) studied specific aspects of learning processes in CSCL including consideration of other teammates' opinions, negotiation of meaning, demonstration of mutual understanding, achievement of consensus, problem-solving, and time and task management issues.

Studies regarding the learning outcomes of CSCL have focused mainly on (quality of) knowledge construction. Both empirical and theoretical studies indicate that CSCL can facilitate and foster knowledge construction (Andriessen et al., 2003; Joiner & Jones, 2003; Kanselaar, De Jong, Andriessen, & Goodyear, 2000; Kirschner, Buckingham Shum, & Carr, 2003; Lipponen, 2002; Weinberger & Fischer, 2006). Students construct not only cognitive knowledge but also metacognitive knowledge in CSCL environments (Clark, Sampson, Weinberger, & Erkens, 2007; Clark, Stegmann, Weinberger, Menekse, & Erkens, 2007; Oestermeier & Hesse, 2000; Veldhuis-Diermanse, 2002; Weinberger & Fischer, 2006). Moreover, it has been demonstrated that CSCL can promote higher-order thinking and problem-solving and, thus, can lead to deeper understanding of the topic (De Jong, Veldhuis-Diermanse, & Lutgens, 2002; Marttunen & Laurinen, 2001; Van Bruggen, 2003; Van Bruggen & Kirschner, 2003; Veerman, 2000, 2003; Veldhuis-Diermanse, 2002).

As mentioned earlier, a crucial issue in CSCL research is the relation between learning processes and learning outcomes. Or, in other words, do successful and less successful students in terms of learning outcomes in CSCL differ with respect to their learning processes? Several empirical studies have focused on qualitative differences in students' learning processes, but these studies have mainly been aimed at specific aspects of learning processes and not at studying the learning process as a whole (i.e. taking different learning process variables into account in combination) and have not explicitly assessed and analyzed the students' learning outcomes. These research studies revealed that there are qualitative differences among students in terms of specific aspects of the learning processes and activities in CSCL environments: the degree to which students discuss and share relevant information while approaching the learning task (Barron & Sears, 2002; Buder & Bodemer, 2008; De Wever, Van Keer, Schellens, & Valcke, 2007); the degree to which students focus on both on-task and off-task activities (Buder & Bodemer, 2008; De Wever et al., 2007; Newman, Webb, & Cochrane, 1995; Van der Pol, Admiraal, & Simons, 2008); the number of messages shared by students while discussing a topic for mutual understanding (Clark, Sampson, et al., 2007; Clark, Stegmann, et al., 2007; Jeong & Chi, 1997; Munneke, Andriessen, Kanselaar, & Kirschner, 2007); the degree to which students broaden and expand their shared knowledge (Baker et al., 2007; Barron & Sears, 2002; Jeong & Hmelo-Silver, 2008; Munneke, 2007; Van Amelsvoort et al., 2007); and the degree to which students provide evidence and examples to support and justify their statements and points of view in CSCL environments (Baker et al., 2007; Munneke, 2007; Munneke et al., 2007). Moreover, successful students in terms of learning processes and activities engage more in dividing the task into sub-tasks and focus more on relevant and on-task activities than less successful students in CSCL environments (Joiner & Issroff, 2003); they also engage in more elaboration activities and make more attempts to resolve conflicts in understanding through elaborated responses (Andriessen, 2006; Barron & Sears, 2002; Munneke et al., 2007; Victor, 1999); they use broader and deeper argumentations in their discussions (Baker et al., 2007; Jeong & Hmelo-Silver, 2008; Munneke, 2007; Van Amelsvoort et al., 2007; Victor, 1999); and they justify their statements and problem solutions in a more logical and reasonable way (Andriessen, 2006; Clark, Sampson, et al., 2007; Clark, Stegmann, et al., 2007; Munneke et al., 2007; Van Amelsvoort et al., 2007). These studies, however, have not explicitly unraveled the relations between learning processes and learning outcomes in CSCL by examining differences in learning processes between successful and less successful students in terms of learning outcomes.

To summarize: (1) up until now, the number of empirical studies explicitly examining the relations between learning processes and learning outcomes in CSCL has been rather limited; (2) the majority of the studies on CSCL has focused on specific aspects of learning processes in CSCL and not on learning processes variables in combination. For these reasons, a comprehensive picture of the relations between learning processes and learning outcomes in CSCL is still lacking. Moreover, in most studies, the level of analysis considered the utterances of individual students and not the utterances of pairs or groups of students learning together in CSCL environments (the joint contributions of the students in a pair or group) (De Wever et al., 2007; Hox & Maas, 2002; Stahl, 2002). Using the joint utterances of the students in a pair or group as the unit of analysis makes it possible to analyze their joint learning processes as building shared understanding (Cress, 2008).

This article seeks to contribute to the existing literature on learning in CSCL environments by comparing the learning processes of pairs of students who are successful and less successful with respect to the quality of knowledge construction. As mentioned earlier, in CSCL research it is common to operationalize learning outcomes in terms of quality of knowledge construction. To construct a comprehensive picture of learning processes and to analyze their nature and quality in-depth, several process variables will be taken into account in combination (which is an original aspect of this research): relevance, correctness, width and depth of discussion and justification and reasoning. The research question is: what are the differences in learning processes (in terms of relevance, correctness, width and depth of discussion and justification and reasoning) between successful and less successful pairs of students (in terms of knowledge construction) in CSCL environments?

2. Method

2.1. Participants

Forty-four students from a human nutrition and health program at Wageningen University in The Netherlands participated in this study. All subjects were enrolled in a 168-h course 'Exposure assessment in nutrition and health research', a compulsory course for MSc students and a restricted optional course for BSc students. In this course, students acquire insight into the methodology of assessment of food and nutrient intake: students are expected to gain insight into the relation between the following research design components: potential systematic and random errors in exposure assessment and the purposes, design, analysis, and interpretation of studies that aim to evaluate dietary assessment methods.

2.2. Procedure

As a pretest to assess the quality of their prior knowledge before CSCL, students were given 45 min to individually design and analyze the essential aspects of an evaluation study (purposes, the required type of information, the potential systematic and random errors, and the design of the evaluation study) which aimed to evaluate a certain dietary assessment method (a 24-h recall) that was used to assess vitamin D intake in a population of immigrants. After this pretest, students were randomly assigned to pairs and given 90 min to discuss in the CSCL environment (see next section for more details) the essential aspects of the evaluation studies developed by both students. Before carrying out this CSCL task, students were given a 20-min introduction to the CSCL environment. After the CSCL task, students had to do an individual posttest to assess the quality of knowledge construction after collaborative learning: they had to re-design the same evaluation study individually within 45 min based on what they had learned in the CSCL task.

2.3. CSCL environment

In this study, students used the platform DREWLITE (see Fig. 1). This is a simplified version of DREW, which was developed within the SCALE project to support argumentative CSCL (Corbel et al., 2002). The 'lite' version is less advanced in managing sessions and traces, which was irrelevant in our study. The platform comprises different tools for communication, collaboration, and argumentation such as chat, graph, text board, view board, and multimodules. DREWLITE modules can be used both individually and collectively. For the present study both individual (for the pretest and the posttest) and collaborative versions (for the CSCL task) were used. During the pretest and the posttest, individual students used the graph module to construct a representation of the essential aspects of the evaluation study (purposes, the required type of information, the potential systematic and random errors, and the design of the evaluation study): students did so by entering text in boxes (see Fig. 1). Moreover, each student could individually provide textual comments and express his or her own opinion in favor of or against given arguments (see Fig. 1): Fig. 1 shows how students related graphs and textual comments during pretest and posttest. For the CSCL task, a chat module was employed which allowed pairs of students to discuss the essential aspects of the evaluation study and to compose a collaboratively written text (see Fig. 2). The students' contributions were automatically recorded in a log-file.

2.4. Measurements

In the current study, two coding schemes were used to analyze the students' learning outcomes and their learning processes in CSCL. For analyzing the quality of the students' learning outcomes, an already available content analysis instrument was used. This coding scheme had already been tested on the criteria completeness, clarity, applicability, accuracy, precision, objectivity, validity, reliability, and replicability (see for more details Veldhuis-Diermanse (2002)). To measure all learning process variables mentioned in the research question of this study, however, a new coding scheme had to be developed to analyze the learning processes of the student dyads since no such comprehensive instrument was available. Both instruments will be described in the next paragraphs.

The coding scheme designed by Veldhuis-Diermanse (2002) to analyze students' learning outcomes in terms of knowledge construction was based on the SOLO taxonomy (Biggs & Collis, 1982) – a hierarchical representation of the structure of observed learning outcomes. The coding scheme of Veldhuis-Diermanse provided a series of categories for ranking the complexity of students' contributions as a proxy of their level of knowledge construction in the pretest and the posttest. Veldhuis-Diermanse et al. (2006, pp. 48) mentioned that: "As students proceed in their learning process, the outcomes of their learning display comparable stages of increasing structural complexity". The original SOLO taxonomy consisted of five hierarchical levels (Biggs, 1999; Biggs & Collis, 1982; Jackson, 2000) from basic to advanced: E = prestructural (which reflects the lowest level of understanding, or no understanding at all); D = unistructural; C = multistructural; B = relational; and A = extended abstract (which reflects the highest level of understanding). Veldhuis-Diermanse (2002) further operationalized this coding scheme by identifying and describing corresponding verbs for each of the levels (except for the lowest level E). In the current study, Veldhuis-Diermanse's coding scheme was used, but again with the addition of level E (see Table 1).

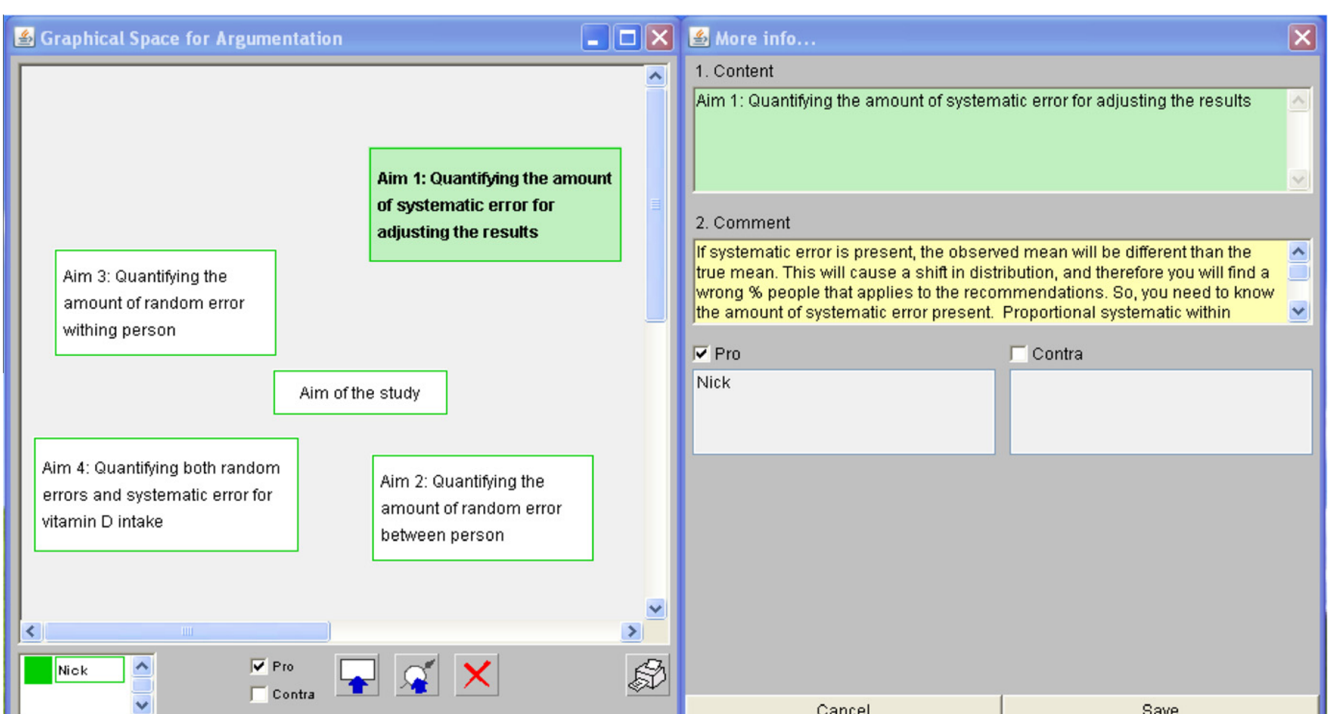

Fig. 1. The interface of the DREWLITE graph module including input text fields for content and comments.

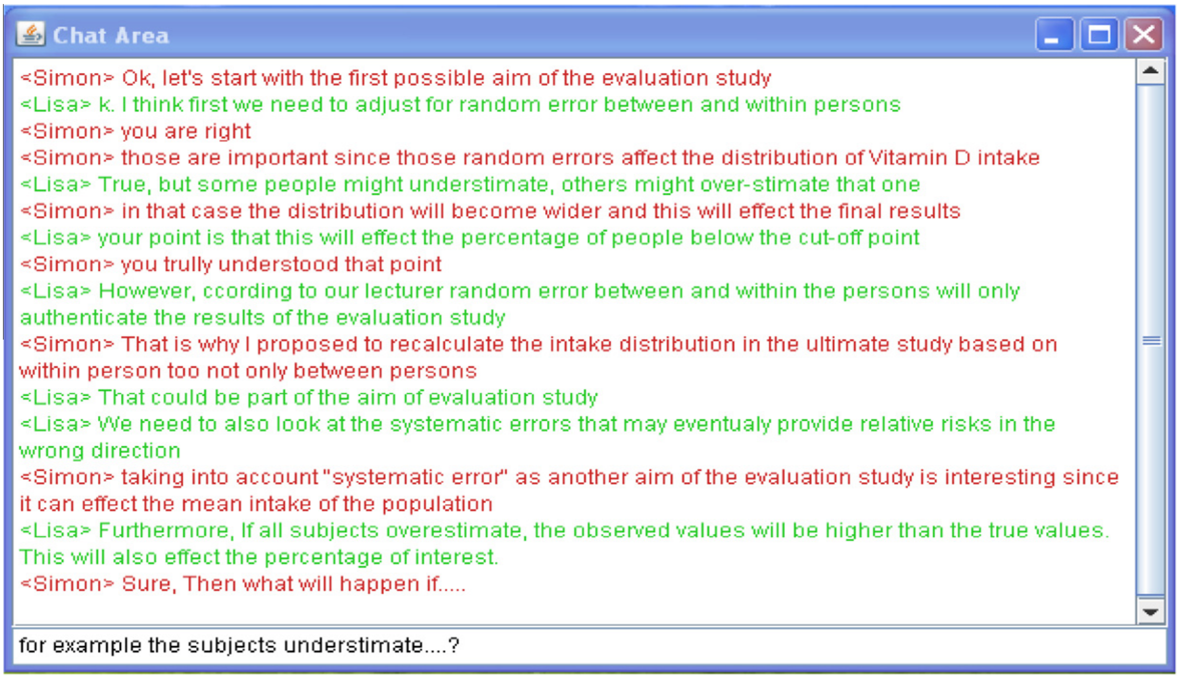

Fig. 2. The interface of the DREWLITE chat module including a shared environment for students to chat, discuss, and argue about the topic.

Table 1
Coding scheme to assess the quality of knowledge construction (level E = basic; level A = advanced) (based on Biggs and Collis (1982) and Veldhuis-Diermanse (2002)).

Level	Signifier	Description
E Prestructural (no understanding at all)	–	Student makes irrelevant contributions which reflect outside (off-task) activities
D	Identify	Student recognizes or distinguishes something as being different. One point or item is given that is not related to other points in the discourse. Furthermore, this new point is not elaborated
Unistructural (understanding as nominal)	Define	Student describes something clearly. The description is taken over from a text or someone else; it is not a self-made definition
C	List/enumerate/number	Items are listed in a particular or random order. Items are marked with a number, usually starting at one
Multistructural (understanding as knowing about)	Describe/organize	A self-made definition of something is given (e.g. a theory, idea, problem or solution) which explains distinguishing features of that thing Ideas or theories are organized, but descriptive in nature. No deeper explanatory relations are given, just a rough structure of information
	Classify	Items are divided into groups or types so that those with similar characteristics are in the same group
B Relational (understanding as appreciating relationships)	Explain	Reasons are given for a choice made An idea, theory or line of thought is elaborated
	Relate/combine	Two or more related things or facts are linked
	Compare/contrast/apply	Things are considered and differences or similarities between them are discovered Acquired knowledge is used in the same or a different situation
A Extended abstract (higher level of abstraction; understanding as far transfer and as involving metacognitive knowledge)	Reflect/conclude	Arguments on relevance and truth are criticized After considering relevant facts the student decides that something is true or false A judgment is given after considering an argument or theory. (The conclusion has to be a point; it must rise above earlier statements, not just be a summary.)
	Generalize/theorize/hypothesize	Concrete ideas are surpassed and the student formulates his or her own view or theory The student predicts that something will be true because of various facts; this prediction has to be checked or examined

This coding scheme was used to quantify the quality of knowledge construction. Student contributions in the comment screens of the DREWLITE platform in the pretest and the posttest were segmented into meaningful units and subsequently, each unit was labeled following the coding scheme described in Table 1. Corresponding verbs were identified for each of the five quality levels to assess the learning outcomes. Student contributions were given points according to their level in the coding scheme: 1 point for category E contributions, 2 points for D, 3 for C, 4 for B, and 5 for A level contributions. Subsequently, the points for the contributions of each student were added together and this number was then divided by the number of meaningful units, which resulted in an individual mean score for the quality of knowledge construction in the pretest and a mean quality score for the posttest. Scores of two inactive students were excluded from the analysis due to the limited number of their contributions, which means that for data analysis 42 students were included in the study.

As mentioned earlier, based on extensive analysis of scientific literature on learning processes in CSCL (see references in Table 2), a new content analysis instrument was developed and used in this study to analyze the learning processes of the student pairs. The CSCL contributions of 21 pairs of students were used as data sources. To analyze their learning processes, the joint contributions made by each pair in their discussion and jointly written text (as recorded in the DRWELITE log-file), were segmented into meaningful units and each unit was labeled following the coding scheme described in Table 2. The following learning process variables were scored for each meaningful unit (or topic): relevance, correctness, width and depth of discussion and justification and reasoning. *Relevance* has to do with the degree to which each contribution of the particular pair of students is content-related. *Correctness* pertains to the degree to which theories and information related to essential aspects of the evaluation study are discussed in an appropriate and accurate way. *Width of discussion* has to do with the degree to which the essential aspects of the evaluation study are broadly discussed. *Depth of discussion* has to do with the degree to which theories and information related to essential aspects of the evaluation study are elaborated in-depth. *Justification and reasoning* has to do with the degree to which a particular pair of students supports and justifies their arguments by using examples, proofs, reasonable evidence, and logical words related to essential aspects of the evaluation study. Moreover, the *number of meaningful contributions* (units) of each student pair was registered.

For each meaningful contribution, a score was assigned for each of the process variables. Pairs of students were given one point for each level 1 assessment (e.g. irrelevant), two points for each level 2 assessment (e.g. partly relevant), and three points for each level 3 assessment (e.g. relevant). Points for the various learning process variables were assigned based on content information and guidelines from the teachers of the course. Thus, the teachers of the course helped coders to get in-depth insight into the content-related topics (on assessment in nutrition and health research). Subsequently, all points assigned to each pair of students per process variable were added together and this number was then divided by the number of meaningful units in order to calculate the mean quality score for each learning process variable. Thus, for each aspect of the learning process, pairs of students could get a mean quality score of between one and three.

2.5. Data analysis

In order to investigate the differences in learning processes between successful and less successful pairs of students in CSCL environments, the data collected for analyzing learning processes and learning outcomes were combined.

First, a mean quality score for knowledge gain was calculated for each individual student by measuring the difference in mean quality score for knowledge construction from pretest to posttest ($M = t2 - t1$). Based on their mean quality scores for knowledge gain and using the median as the criterion, 9 pairs of students could be classified as successful, 9 pairs as less successful and 3 pairs as mixed (combinations of one successful and one less successful student). These 3 mixed pairs of students were excluded from the analysis. Next, the quality of the learning processes of successful and less successful pairs of students in terms of relevance, correctness, width and depth of discussion and justification and reasoning was compared.

As mentioned earlier, analyses in this study were based on identifying and scoring meaningful units in the students' utterances. The students' utterances were segmented into meaningful units by distinguishing each solution that was mentioned or discussed. A solution comprised of a discussion of the essential aspects of the evaluation study (purposes, the required type of information, the potential systematic and random errors, and the design of the evaluation study). Teachers of the course provided us with all possible solutions in terms of essential aspects of the evaluation study. Students' utterances could include one or more solutions (or meaningful solution units). Since the number of meaningful (solution) units could be determined unambiguously, no inter-rater reliability calculation was needed for the number of meaningful units. Next, for every meaningful unit, all relevant variables were scored. Thus, for every meaningful unit of a student pair, all categories of the process coding scheme were scored: every meaningful unit received a score on how relevant, how correct, etc. After that, for each student pair, a mean quality score was calculated for each learning process variable.

Although Veldhuis-Diermanse (2002) reported a satisfactory (0.72) inter-rater reliability for her coding scheme, the inter-rater reliability for the coding scheme for learning outcomes was calculated in this study as well. Two coders analyzed the students' contributions using the coding schemes described above. Cohen's kappa was employed as a reliability index of inter-rater agreement. Cohen's kappa was 0.78 (pretest) and 0.81 (posttest) for the slightly revised coding scheme for learning outcomes, and 0.81 for the new coding scheme for learning process variables, which indicates acceptable levels of agreement. Moreover, intra-coder test–retest reliability was calculated for 20% of the contributions. This resulted in identical scores in 85% of the contributions for the coding scheme for learning outcomes and in 83% of the contributions for the coding scheme for learning process variables.

3. Results

Before answering the research question (What are the differences in learning processes in terms of relevance, correctness, width and depth of discussion and justification and reasoning between successful and less successful pairs of students in terms of knowledge construction in CSCL environments?), the characteristics of (pairs of) students' learning outcomes and processes in this study will be discussed first.

3.1. Characteristics of students' learning outcomes

During the pretest, 514 meaningful units were produced by the students ($M = 12.23$; $SD = 3.58$; $Max = 21$; $Min = 7$). During the posttest, the total number of meaningful units was 531 ($M = 12.64$; $SD = 3.10$; $Max = 20$; $Min = 6$). Repeated measurement analysis showed that this difference was not statistically significant ($F = 0.44$; $p = 0.61$). With respect to the quality of *knowledge construction*, the majority of students' contributions were assessed as level C (multistructural) or level B (relational): approximately 63% for the pretest and 65% for the posttest. The percentages of contributions assessed as level E (prestructural) or level A (extended abstract) were considerably lower for both tests (see Fig. 3).

Students' mean quality scores for *knowledge construction* were 3.01 ($SD = 0.40$) for the pretest and 3.11 ($SD = 0.34$) for the posttest. This difference was statistically significant ($F = 5.62$; $p < .05$). More specifically, significant differences were found for the *knowledge construction* levels E (prestructual; $F = 6.22$; $p < .05$) and A (extended abstract; $F = 7.68$; $p < .05$) between pretest and posttest: in the posttest, students constructed fewer (lowest) level E contributions and more (highest) level A contributions than in the pretest. No significant differences between pretest and posttest were found for *knowledge construction* levels B (relational; $F = 1.62$; $p = 0.21$), C (multistructural; $F = 0.68$; $p = 0.42$), and D (unistructural; $F = 0.02$; $p = 0.90$).

Table 2
Coding scheme to analyze the quality of learning processes of student pairs in CSCL with process variables, levels and corresponding descriptions, and references.

Relevance	(1) Irrelevant	Topic that does not contribute to completion of the task	Newman et al. (1995), Buder and Bodemer (2008), Van der Pol et al. (2008), De Wever et al. (2007)
	(2) Partly relevant	Topic that does not directly relate to completion of the task, but might contribute to understanding the task	
	(3) Relevant	Topic that needs to be brought up during discussion to allow for successful completion of the task	
Correctness	(1) Incorrect	Theories and studies are described incorrectly	Barron and Sears (2002), Buder and Bodemer (2008), De Wever et al. (2007)
	(2) Partly correct	Due to the incompleteness of a statement, the discussion cannot be regarded as correct	
	(3) Correct	Theories and studies are described correctly	
Width of discussion	(1) Inadequate	Not enough topics are provided to complete the task	Barron and Sears (2002), Baker et al. (2007), Van Amelsvoort et al. (2007), Jeong and Hmelo-Silver (2008) Munneke et al. (2007)
	(2) Partly adequate	Not enough topics are provided to complete the task successfully	
	(3) Adequate	Enough topics are provided to complete the task successfully	
Depth of discussion	(1) Superficial	Topic is not discussed or elaborated on or the topic is discussed in an insignificant way	Baker et al. (2007), Van Amelsvoort et al. (2007), Victor (1999), Jeong and Hmelo-Silver (2008), Munneke et al. (2007)
	(2) Simple	Simple explanations or interpretations are given. The topic is discussed in a way that contributes partly to the advancement of the task completion	
	(3) Elaborated	Detailed and elaborated explanations or interpretations are given. The topic is discussed in a way that contributes significantly to completion of the task	
Justification and reasoning	(1) Illogical	Argument is not convincing or logical. Evidence and logic are weakly connected to argument	Munneke (2007), Baker et al. (2007), Van Amelsvoort et al. (2007)
	(2) Incomplete	Due to the incompleteness of a statement, the discussion cannot be regarded as correct	
	(3) Logical	Argument is convincing and logical. Evidence and logic are well-related to argument	
Number of units		Number of meaningful units in discussion and text entered by the particular pair of students	Jeong and Chi (1997), Munneke et al. (2007), Clark, Sampson, et al. (2007), Clark, Stegmann, et al. (2007)

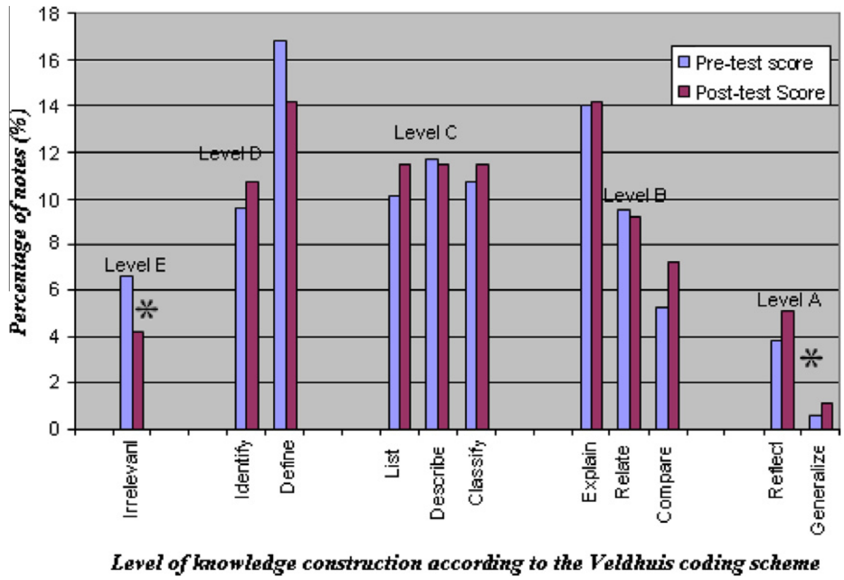

Fig. 3. Students' meaningful units produced during the pretest and the posttest assessed for the quality of knowledge construction (*: mean differences between pretest and posttest for levels A and E are significant at the .05 level).

3.2. Characteristics of successful and less successful students' learning outcomes

During the pretest, 259 meaningful units were produced by successful students ($M = 12.33$; SD = 4.02; Max = 21; Min = 6) and 255 meaningful units by less successful students ($M = 12.14$; SD = 3.16; Max = 21; Min = 7). This difference was not statistically significant ($F = 0.03$; $p = .87$). During the posttest, the total number of meaningful units was 263 ($M = 12.52$; SD = 3.35; Max = 21; Min = 6) for successful students, and 268 for less successful students ($M = 12.76$; SD = 2.91; Max = 20; Min = 7). This difference was not statistically significant either ($F = 0.06$; $p = .81$). Successful students' mean quality scores for *knowledge construction* were 3.03 (SD = 0.44) for the pretest and 3.23 (SD = 0.34) for the posttest. This difference was statistically significant ($F = 18.78$; $p < .001$). Less successful students' mean quality scores for *knowledge construction* were 2.99 (SD = 0.35) for the pretest and 3.00 (SD = 0.29) for the posttest. This difference was not statistically significant ($F = 0.21$; $p = .89$). Less successful and successful students did not differ significantly with respect to their pretest scores ($F = 0.11$; $p = .75$): there appeared to be no significant differences with respect to the prior knowledge of less successful ($M = 2.99$; SD = 0.35) and successful ($M = 3.03$; SD = 0.44) students. Less successful and successful students differed significantly with respect to their posttest scores ($F = 5.15$; $p < .05$): meaning that, during the posttest the mean quality scores of *knowledge construction* was higher for successful students ($M = 3.23$; SD = 0.34) than for less successful students ($M = 3.00$; SD = 0.29).

3.3. Characteristics of students' learning processes

Descriptive analyses were used to describe the learning processes of the student pairs in terms of *relevance, correctness, width and depth of discussion and justification and reasoning* (see Table 3). In total, 264 meaningful discussion units were produced by the student pairs ($M = 12.57$; SD = 2.06; Max = 16; Min = 9). About 20–35% of the students' contributions could be characterized as *irrelevant, incorrect, inadequate, superficial, or illogical* (see Table 3).

Table 3
Characteristics of students' learning processes in CSCL: frequencies and percentages for the various levels of the learning process variables.

Variable	Levels	Frequency	Percentage
Relevance	Irrelevant	52	19.69
	Partly relevant	82	31.06
	Relevant	130	49.24
Correctness	Incorrect	69	26.13
	Partly correct	73	27.65
	Correct	122	46.21
Width of discussion	Inadequate	74	28.03
	Partly adequate	78	29.54
	Adequate	112	42.42
Depth of discussion	Superficial	87	32.95
	Simple	71	26.89
	Elaborated	106	40.15
Justification and reasoning	Illogical	92	34.84
	Incomplete	71	26.89
	Logical	101	38.25
Number of meaningful units	–	264	100

3.4. Relation between learning outcomes and learning process

Next, to answer the research question, successful and less successful student pairs were compared in terms of the learning process variables mentioned earlier. Successful pairs of students in terms of *quality of knowledge construction* appeared to have higher scores on the following learning process variables than less successful students: *relevance, width and depth of discussion and justification and reasoning* (see Table 4). In other words, successful pairs of students produced *more relevant, more logical, and broader and deeper discussions and arguments* than less successful pairs of students during the learning process in the CSCL environment. The difference between successful and less successful students with respect to the variable "*correctness*" was just below the significance level. The difference between the two groups of students in terms of *numbers of meaningful units* was not significant (see Table 4).

4. Conclusion and discussion

The results of the present study showed a significant improvement in the quality of students' knowledge construction from pretest to posttest. Several authors have indeed claimed that CSCL has an added value in terms of learning outcomes, especially the

Table 4
Successful and less successful pairs of students compared in terms of learning process variables.

Variable	Labels	Mean	SD	t	Sig.
Relevance	Successful	2.39	.21	3.66[a]	.002
	Less successful	2.06	.25		
	Total	2.23	.24		
Correctness	Successful	2.30	.22	1.72	.106
	Less successful	2.12	.20		
	Total	2.21	.22		
Width of discussion	Successful	2.34	.12	3.75[a]	.002
	Less successful	1.91	.32		
	Total	2.12	.32		
Depth of discussion	Successful	2.33	.29	3.15[a]	.006
	Less successful	1.96	.20		
	Total	2.15	.31		
Justification and reasoning	Successful	2.30	.24	3.17[a]	.001
	Less successful	1.87	.18		
	Total	2.09	.30		
Number of meaningful units	Successful	12.44	2.06	−0.45	.656
	Less successful	12.88	2.08		
	Total	12.66	2.02		

[a] Significant at the .05 level.

quality of knowledge construction (Andriessen et al., 2003; Joiner & Jones, 2003; Kanselaar et al., 2000; Kirschner, 2003; Lipponen, 2002; Weinberger & Fischer, 2006). There could be several reasons for this. In CSCL students can discuss their ideas and conceptions from different perspectives in order to re-construct and co-construct (new) knowledge while solving authentic and complex problems (Veldhuis-Diermanse et al., 2006; Weinberger & Fischer, 2006). Furthermore, through writing notes in CSCL environments, students can re-construct their thoughts while formulating and organizing ideas and opinions and they can also re-read posted notes by looking at the conversation history (De Jong et al., 2002; Veerman, 2000). Writing notes and re-reading and re-thinking those notes are regarded as important tools for learning and knowledge construction in CSCL (De Jong et al., 2002; Veerman, 2000).

The results of the present study also showed that students constructed fewer irrelevant contributions (prestructural) and more contributions of the highest quality (extended abstract) during the posttest than the pretest. It has been shown before that CSCL can lead to higher-order thinking by giving students the opportunity to discover and generate arguments and therefore to further their understanding of the topic (Marttunen & Laurinen, 2001; Veerman, 2000; Veldhuis-Diermanse, 2002). The idea is that students in CSCL environments can discuss, elaborate, and integrate their thoughts and knowledge, which is likely to lead to developing a deeper understanding and higher-order skills (De Jong et al., 2002; Veldhuis-Diermanse, 2002).

As mentioned in Section 1, however, up until now, (1) the number of empirical studies explicitly examining the relations between learning processes and learning outcomes in CSCL has been rather limited; and (2) the majority of the studies on CSCL has focused on specific aspects of learning processes in CSCL in isolation and not on learning processes variables in combination. With respect to this second point, for example, previous studies have shown that engaging in more relevant, sound, and on-task activities (Barron & Sears, 2002; Buder & Bodemer, 2008; Joiner & Issroff, 2003) and making better elaborated (Victor, 1999) and justified contributions to discussions (Baker et al., 2007; Clark, Sampson, et al., 2007; Clark, Stegmann, et al., 2007; Munneke et al., 2007; Van Amelsvoort et al., 2007) as well as making broader and deeper arguments (Baker et al., 2007; Jeong & Hmelo-Silver, 2008; Munneke, 2007; Van Amelsvoort et al., 2007) lead to better quality of knowledge construction processes than engaging in off-task activities and contributing less elaborated and justified and more narrow and superficial arguments and discussions (Weinberger, Stegmann, Fischer, & Mandl, 2007) in CSCL environments. But, for the two reasons mentioned above, a comprehensive picture of the relations between learning processes and learning outcomes in CSCL was still lacking.

The research question of the present study, which aimed at analyzing the nature and quality of these learning processes in-depth, concerned differences in learning process variables between less successful and successful pairs of students in CSCL. This study revealed that successful pairs constructed talk that was more relevant, wider and deeper, more convincing and more logical than less successful pairs (i.e. systematic differences between successful and less successful students in the combination of learning process variables). In other words, the findings showed that individuals who engage in a 'fruitful discussion' (i.e. more relevant, wider and deeper, etc.) gain more knowledge than individuals whose discussion is less fruitful.

In this regard, the current study led to a more comprehensive picture of learning in CSCL environments: based on previous research, several process variables were taken into account (but now in combination, which is an original aspect of this research) and related to the students' learning outcomes: relevance, correctness, width and depth of discussion and justification and reasoning. This made it possible to examine what kinds of interaction appear to aid learning. Being able to determine crucial kinds of interaction opens the door for specific interventions aimed at improving the quality of these interactions: in order to improve students' learning outcomes in CSCL, one should pay explicit attention to the nature of their learning processes in these environments in terms of relevance, correctness, width and depth of discussion and justification and reasoning. These aspects should be addressed in combination, which is a new implication of the present study (compared to previous studies). Without external support in CSCL, one cannot expect that students will broaden and deepen the space of debate with justified and reasonable arguments to a high extent.

The results of this study with respect to the characteristics of the learning processes of students in CSCL showed that about 20–35% of the students' contributions can be characterized as irrelevant, incorrect, inadequate, superficial, or illogical, and another 20–30% as only partly relevant, partly correct, partly adequate, simple, or incomplete, which are considerable percentages. In other words, there is considerable room for improvement through external support. Scripting could be a very crucial factor as an instructional support technique to scaffold learning in CSCL environments (Azevedo & Hadwin, 2005). Some of these scripts could be embedded in CSCL platforms to stimulate students to engage in more relevant, correct, broad, deep, and logical discussions. For example, by using the collaboration and argumentative scripts discussed in the next paragraphs, students can ask clarifying questions and criticize their fellow-students to back up their statements and arguments with more reasonable evidence, examples, etc. Clarifying questions and criticizing could help groups of learners to elaborate, deepen, and broaden their arguments with regard to the topic of discussion.

Collaboration scripts provide detailed and explicit guidelines for small groups of students to clarify what, when, and by whom certain activities need to be executed and how group members should adequately discuss and collaborate to accomplish the learning task (Weinberger et al., 2007). A collaborative social script can be used to specify and sequence the interaction of learners so that they can adopt adequate interaction strategies such as eliciting (asking critical questions to elicit information from their learning partners) and transactivity (responding critically to their partners' contributions) in CSCL environments (Weinberger, Ertl, Fischer, & Mandl, 2005; Weinberger et al., 2007).

Epistemic scripts could be used to structure and sequence discourse activities with respect to content and task strategies (Weinberger et al., 2005; Weinberger & Fischer, 2006; Weinberger et al., 2007), which in turn may help learners to construct sound and correct arguments that contribute to solving problem cases. It has been shown that epistemic and collaborative scripts can reduce off-task activities and help students to discuss relevant, sound, and accurate points and arguments in CSCL environments (Weinberger et al., 2005; Weinberger et al., 2007).

Argumentative scripts can be used to structure and formulate the construction of broad, deep, and justified arguments in CSCL environments (Stegmann et al., 2007; Weinberger et al., 2007). Using specific facilities implemented in the user-interface may encourage the use of grounds (data/warrant/backing), or supporting and elaborating a claim by qualification (qualifier/rebuttal), or constructing a complete argumentation sequence (argument/counterargument/integration) to indicate the consideration of alternative explanations and extended argumentation solutions, which in turn may help learners to broaden and deepen the space of debate (Stegmann et al., 2007; Weinberger et al., 2007). Empirical studies have shown that argumentative scripts can lead to more elaborated, justified, deeper and broader arguments, which in turn can effectively facilitate the specific discourse processes of knowledge construction when it comes to warranting and qualifying claims (Stegmann et al., 2007; Weinberger et al., 2007). In future empirical studies, the effects of different categories of scripts on the different aspects of learning processes in CSCL environments will be examined.

At this point, it is relevant to discuss some strengths and weaknesses of the present study. One of the strengths of this study is that the students' learning processes and outcomes in CSCL were assessed in an authentic educational setting (high ecological validity) in the domain of nutritional research education and not in an artificial experimental setting. This provided the opportunity to shed light on the differences in the learning processes between successful and less successful students as they occur in authentic learning situations (direct practical relevance).

Another strength of this study is its use of two content analysis coding schemes to analyze the students' learning processes and outcomes in CSCL. Although content analysis is a very time-consuming process, it is one of the most frequently applied techniques for analyzing written notes and transcripts of discourse corpora in CSCL environments. Learning outcomes were analyzed by using a slightly revised version of an already available coding scheme developed by Veldhuis-Diermanse (2002), which had already been used in several other empirical studies. Its inter-rater reliability values had been reported as being satisfactory (De Laat & Lally, 2003; Veldhuis-Diermanse, 2002; Veldhuis-Diermanse et al., 2006). In the present study, these values were even higher. Moreover, to analyze the students' learning processes, CSCL literature was reviewed and important aspects of learning processes were taken into account in developing a new coding scheme. This new scheme was used to construct a comprehensive picture of computer-supported collaborative learning. More than satisfactory inter-rater reliability and intra-coder test–retest reliability values for this coding scheme were obtained.

A limitation of this study is that student characteristics which could potentially influence learning processes and outcomes (age, cultural and educational background, experience with CSCL, etc.) were not explicitly taken into account. Gress, Fior, Hadwin, and Winne (2010) listed individual differences between students (with respect to attitude toward collaborative learning, collaborative skills, computer efficiency, leadership abilities, learning skills and styles, metacognitive strategies, and social network from prior collaboration) that need to be taken into account when implementing CSCL environments. Having prior collaborative work experience before working in CSCL environments, for example, can influence the effectiveness of learning in CSCL (Beers, Kirschner, Boshuizen, & Gijselaers, 2007). Observations of students while working on the collaborative learning task in the present study showed that some students needed time to get used to working in CSCL environments even though instructions and hand-outs had been provided in advance. Therefore, before implementing CSCL, it is crucial to provide students with guidelines and instructions as well as extensive opportunities to practice working in the CSCL environment. Finally, it would be interesting to validate the findings of this study through other experimental studies in which students' backgrounds and other characteristics are taken into account in more controlled experimental conditions.

To summarize and conclude, this study revealed that the patterns of learning processes of successful and less successful students in the CSCL environment differ in terms of relevance, width and depth of discussion and justification and reasoning. Previous studies have given the indication that there are differences among students in terms of learning process variables, but this study showed systematic differences of the combination of process variables. These learning process variables seem to be key to higher learning performance in CSCL environments (Koschmann, 1996; Mcdonald, 2003; Stegmann et al., 2007; Veerman, 2000; Veldhuis-Diermanse, 2002).

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