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2010

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Completed Research Paper

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Abstract

This study investigates inquiry-based interaction and learning outcomes mediated by two types of artifact-centered discourse environments. The study aims to promote social construction of knowledge by optimizing the division of mental effort between pragmatic and semantic grounding activities. We present a theoretical research model by combining social constructivism, grounding theory, and cognitive load theory. We carried out a quasi-experimental study using survey instruments, content analysis, sequential analysis, and knowledge tests for a holistic approach to understand the paradox of mental effort in online learning conversations. The primary finding of this study is that a linked artifact-centered discourse environment facilitates pragmatic grounding activities to attain a common ground in online learning conversations. Additionally, less need for pragmatic grounding activities leaves more room for semantic grounding activities. Finally, more semantic grounding activities lead to a deeper understanding of the learning material.

Keywords: Inquiry-based interaction, semantic grounding, pragmatic grounding, artifact-centered discourse

Introduction

Collaborative learning is a popular educational strategy designed to engage learners in activities that stimulate and encourage joint meaning making. Engaging in social interaction not only allows learners to internalize knowledge from others (knowledge sharing), but, more importantly, it also allows learners to actively construct new understanding (knowledge construction). When jointly creating and discovering personal and interpersonal meaning, we can speak of a "community of inquiry" (Stahl & Hesse, 2007). As argued by Onrubia and Engel (2009), learners in a community ideally extend, deepen, and transform meaning by building on each other's contributions. For instance, Mäkitalo, Weinberger, Häkkinen, Järvelä, and Fischer (2005) have found that asking thought-provoking questions, evaluating suggestions, elaborating explanations, and summarizing seem to be especially effective for moving from individual to joint meaning making.

Offering amongst others a persistent collaboration history, computer-mediated communication tools provide good opportunities to engage students in the activities described above. Communication within these systems can be either synchronous, asynchronous, or a combination of both. As an asynchronous system, an online discussion forum allows students to prepare, think, reflect, and search for additional information during participation in discourse (Pena-Shaff & Nicholls, 2004). Therefore, online asynchronous discussion can facilitate a natural setting for effective social knowledge construction.

However, in spite of these advantages, many studies have demonstrated that the type of interaction necessary for high levels of knowledge construction or truly conversational modes of learning is often lacking in practice (Janssen, Erkens, & Kanselaar, 2007; Yang, Newby, & Robert, 2008). Numerous studies report the difficulty of establishing and maintaining a common ground or shared communicative context as a pressing problem in online discussions (Cobos & Pifarré, 2008; Engelmann, Dehler, Bodemer, & Buder, 2009; Häkkinen & Järvelä, 2006). According to Suthers (2006), this particular problem relates to the delayed and non-verbal feedback features of the communication medium as well as the absence of shared contextual cues. This limited common ground poses a serious barrier to collaborative knowledge construction because providing counterarguments reflecting different perspectives on a specific topic becomes more challenging, which hinders the subsequent elaboration of the thinking processes (Baltes, Dickson, Sherman, Bauer, & LaGanke, 2002; Ding, 2009). Therefore, the objective of this study is to promote social construction of knowledge in online discussions by facilitating students' effort to build and maintain a common ground. To achieve this objective, we will experimentally investigate two functional characteristics of a linked artifact-centered discourse environment (see Takeda & Suthers, 2002). Our basic research premise is that directly addressing a part of a text by annotating it and then using that annotation to organize all messages referencing that part will assist students in establishing and maintaining a common ground for the production of rich and constructive interactions.

The rest of the paper is organized as follows. First, we will explore the essential elements of effective inquiry-based interaction in order to develop a theoretical research model. We will then discuss community of inquiry, tools, and learning material as conditions for effective inquiry-based interaction, leading to an extended research model and the hypotheses of the present study. After describing the research method and presenting the results, we will conclude with a discussion of the findings, their implications for practice, limitations, and some directions for future research.

Effective Inquiry-Based Interaction

A constructivist epistemology emphasizes that mental effort focusing on the active and meaningful processing of the learning material is indispensible for deep learning. Active processing of the learning material is important because only by "struggling" with the learning material (discovering, constructing, practicing, and validating it), will allow the learner to deeply store and remember it (Hiltz, Coppola, Rotter, & Turoff, 2000). Meaningful processing of the learning material is important because it ensures newly created understanding integrated into a person's existing base of knowledge, leading to a subjective appropriation of it. This ensures that the learner will be able to recollect and apply it in different concrete situations. Thus, constructivism emphasizes the value of the process and of "trying to understand." More concretely, Mayer and Moreno (2002) argue that the active construction of meaning involves three types of interaction with the learning material: selecting relevant information, organizing it into coherent representation, and integrating it with other knowledge. Similarly, Suthers, Vatrapu, Medina, Joseph, and Dwyer (2008) argue that a learner's interactions with the learning material should be elaborative, integrative, and reflective.

Taking an "interactionist" view (Suthers, 2006), we believe that although learning may primarily be a process within an individual mind, it can be enhanced through interactions with others. This perspective holds that construction of knowledge involves two types of interaction: one between the learner and the objects of learning (Piaget, 1977) and the other between the learner, teacher, and other students (Vygotsky, 1978). Consistent with this perspective, many educational technology researchers place greater emphasis on constructivism in its social form ("social constructivism") to advocate that learning is not only active but also interactive. Hiltz (1994) supports the importance of social interactions by stating that "the social process of developing shared understanding through interaction is the natural way for people to learn" (p. 22). A social constructivist view might maintain that individual cognitive development is the result of a spiral of causality: an initial understanding of the respective subject matter allows participation in social interaction, which produces new understanding of the subject matter which in turn, makes possible more sophisticated constructive interaction, and so on (Dillenbourg, Traum, & Schbeider, 1996).

Although learning can be enhanced through the introduction of social interaction, this interaction also introduces a new level of coordination and regulation of the interaction process itself. As pointed out by Häkkinen and Järvelä (2006) students engaged in peer discourse are continuously faced with the task of establishing and maintaining a common ground because of the existence of different views, different meanings of concepts, and different frames of reference. This process of continuous construction and maintenance of common ground is a central part of human communication in general, and is defined by linguistics (Clark and Wilkes-Gibbs, 1986) as grounding. Grounding is a central mechanism in human communication and consists of monitoring shared understanding, for instance by checking or paraphrasing other's comments, and, if needed, of repairing misunderstanding. Grounding is also a key element in collaborative learning, where learning is generated not only by the effort invested in understanding the learning material, but also the mental effort invested in understanding one's peers. However, grounding processes have many different forms and shapes. Constructivism dealing with individual learning processes could easily state that "all mental effort is good." However, collaborative situations require a more nuanced view. While putting effort into the meaningful processing of the learning material is still the core that generates learning, collaboration also requires effort to be devoted to the collaborative process itself. As Withworth, Gallupe, and McQueen, (2000) found, communicators need to manage interpersonal relations and group functioning. Likewise, Janssen et al. (2007) showed that collaborative learners often face social interaction problems regarding communication and coordination. These problems can be even greater in computer-mediated communication. As Gunawardena (1995) noted "social interactions tend to be unusually complex because of the necessity to mediate group activity in a text based environment" (p. 148). Consequently, Cakir, Zemel, and Stahl (2009) confirmed that students working together by using an online discussion system must enact or invent ways of coordinating their understandings and structuring their interaction. This coordination process seems necessary to create the right conditions for learning, but may not directly generate any learning. Especially with complex and demanding collaborative tasks, for example, students may need to talk a long time about the process and form their collaboration, before they can actually start processing the learning material itself. In other words, although all communication revolves around grounding, not all communication necessarily leads to learning. Therefore, when talking about the relation between social interaction and learning, the traditional concept of grounding as borrowed from the communication science seems to be too generic and in order to investigate this link more closely, we need to be more specific.

Baker, Hansen, Joiner, and Traum (1999) identified two forms of grounding processes necessary for joint meaning making. The first one, pragmatic grounding, refers to a conversational participant attempting to understand a partner's communicative intentions. The second one, semantic grounding, is about the effort put into constructive interactions after understanding communicative intentions. Semantic grounding is in line with Dillenbourg et al.'s (1996) notion of negotiation, which may involve identifying areas of agreement and proposing new co-constructions on topics where cognitive differences exist. According to Baker et al. (1999), semantic level grounding relates closely to learning. Thus, pragmatic grounding activities form the bottom layer of semantic grounding activities.

Cognitive load theory may help to further elaborate our more nuanced view on the role of grounding in collaborative learning. As we have described, constructivism mainly focuses on maximizing mental effort. However, cognitive load theory aims to optimize mental effort that is committed to a learning task. As described by Gerjets and Scheiter (2003), cognitive load theory starts from the constraints of working memory capacity to optimize learning processes. Cognitive load represents the load that a particular task imposes on a learner's cognitive resources (Gerjets & Scheiter, 2003; Van Merriënboer, Kirschner, & Loesbeth, 2003). The cognitive capacity an individual can allocate to a task is similar to the concept of mental effort that we know from constructivism. The central tenet of cognitive load theory is that human cognitive architecture has limited information processing capacity with regard to the amount of information it can handle in parallel in working memory. Accordingly, Van Merriënboer et al. (2003)

explained that the theory provides three guidelines to circumvent the limitation. First, it prevents cognitive overload; second, it minimizes the extraneous cognitive load (the load that does not contribute to learning); third, it maximizes germane cognitive load (the load spent directly on learning) within the limits of total available cognitive capacity. Combining social constructivism, grounding theory, and cognitive load theory, we can now consider pragmatic grounding activities as extraneous grounding efforts and semantic grounding activities as germane grounding efforts.

Based on the previously described theories, we can now construct a synthesized theoretical research model. Figure 1 depicts our conceptualization, centering on semantic (constructive interactions) and pragmatic (interaction costs) grounding activities in an inquiry-based interaction. We use this representation to argue that due to a maximum of available mental effort, pragmatic grounding activities can potentially inhibit semantic grounding activities and hinder deep understanding of the learning material. The model postulates that pragmatic grounding activities form the bottom layer of the semantic grounding activities, which relate to the generated learning outcomes. Pragmatic grounding involves two activities necessary for carrying an inquiry-based interaction: establishing a shared frame of reference and maintaining discourse coherence. Establishing a shared frame of reference involves a student verbally referencing a contribution to a certain passage from the learning material and another student's attempt to access that passage by using the verbal reference (comprehensive or demonstrative) provided within the contribution. Maintaining discourse coherence refers to finding conceptually relevant contributions. Semantic grounding activities concern constructive interactions that support learning in group interaction. Ding (2009), Suthers (2006), and Baker et al. (1999) found that the identification of cognitive differences and subsequent elaboration of thinking processes are perhaps the most important mechanisms contributing to collaborative learning. According to these studies, collaborative knowledge construction starts with learners externalizing their knowledge by elaborating on and comprehensibly explaining their understanding to their learning peers. Then, cognitive difference arises as a product of a community of inquiry to reflect the gap in knowledge between peer learners. One way to bridge the knowledge gap between collaborating learners is negotiation of meaning that may allow students to correct, re-structure, and expand their knowledge in order to promote their conceptual understanding.

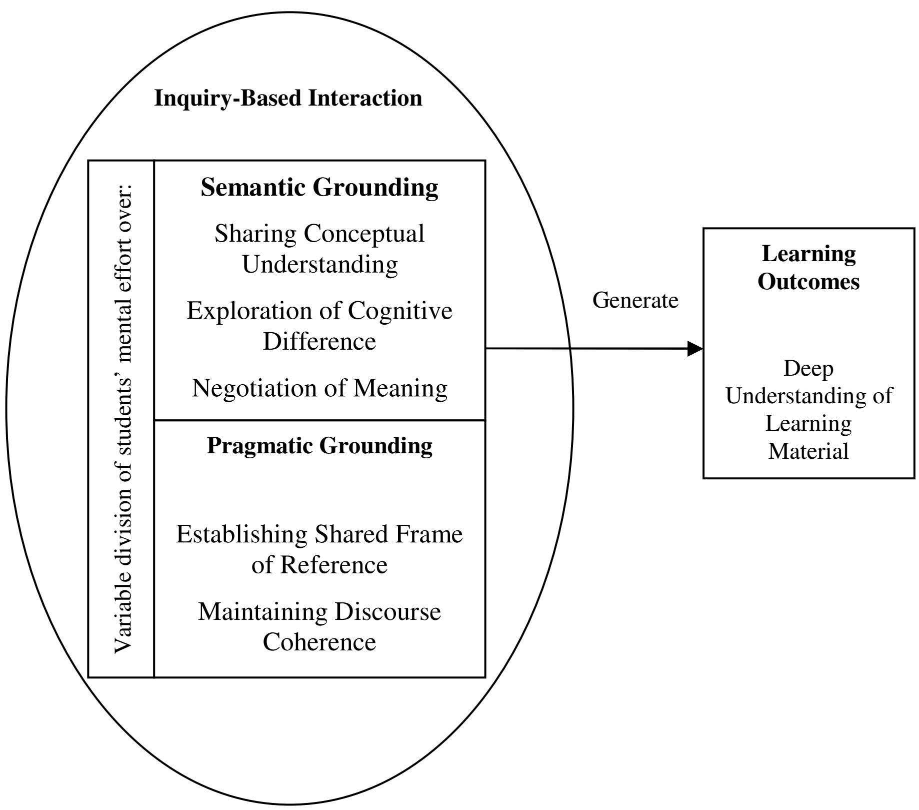


Figure 1. Theoretical Research Model

Conditions for Effective Inquiry-Based Interaction

Semantic and pragmatic grounding activities in an inquiry-based interaction depend upon three high-level variables: community of inquiry, tool, and learning material. We will now explain these variables in detail.

Community of Inquiry

The community of inquiry (Garrison & Arbaugh, 2007) focuses on the intentional development of an online learning community to nurture collaborative knowledge construction through three forms of presence: social, cognitive, and teaching. The social presence component focuses attention on creating a sense of belonging that supports meaningful inquiry. This facet is significant for a “cognitive,” “on-topic,” “on-task,” and “sustained” discussion (Guzdial & Turns, 2000) because without a sense of belonging, students may be anxious and unwilling to express their tentative thoughts, which can be seen as the essential building blocks for their collaborative knowledge construction (Van der Pol, Admiraal, & Simons, 2006). According to Garrison and Arbaugh (2007), cognitive presence emphasizes “the process of both reflection and discourse in the initiation, construction, and confirmation of meaningful learning outcomes” (p. 4). Teaching presence concerns the design, facilitation, and direction of cognitive and social processes that support meaningful and educationally worthwhile learning outcomes. Thus, it refers to the didactical part of the learning process, both in design (such as tasks or evaluation) and in the process itself (guidance and moderating).

Tool

This study builds on two types of artifact-centered discourse systems (see Takeda & Suthers, 2002) to find a natural solution for the pressing problem of attaining a common ground in online learning conversations. We specifically investigate these types of systems because peer discourse in online discussion has a tendency to drift away from relevancy into trivialities without a concrete shared context to create knowledge. In line with this thought, artifact-centered discourse systems may help to maintain the focus of peer discourse on the relevancy of the learning material by enabling students to conduct discussions in the context of an artifact. This section describes two software environments based on the anchored discussion tool developed by J. van der Pol. Presently, an artifact in these environments is a PDF document, and users view each page of a PDF document in the form of a GIF image format. At the most basic level, we agree with Dennen (2008) that these systems are empty shells waiting to be filled by learners.

Students can collaborate in these environments in two ways. First, students can read an interesting discussion thread; refer to the relevant part of the document to grasp the status of the discourse; and write their own contribution that will move collaborative knowledge construction forward. Second, students can read a document in search of an interesting topic; assess the status of the discourse associated with that topic; and articulate their ideas to advance collaborative knowledge about the subject at hand.

Parallel Artifact-Centered Discourse Environment

The notion of “artifact-centered discourse” (Suthers, 2001) focuses on the problem of designing computer-mediated communication technologies in order to promote more on-topic discussions. The parallel artifact-centered discourse environment (Figure 2) places a conventional threaded discussion forum in one frame and the relevant learning material in an adjoining frame to create a close coupling between peer discourse and study material. The forum retains the reply structure and chronology of the discourse based on the historical development of the discussion. Other examples of parallel artifact-centered discourse systems include the Text Software Environment (Suthers et al., 2008) and Digital Document Discourse Environment (Uren, Buckingham, Li, Domingue, & Motta, 2003). Moreover, although most of the existing online learning systems (such as Blackboard) offer learning material and the discussion forum in entirely separate windows, Suthers (2001) observed that a cognitively active learner can work around this problem by manually opening two windows and placing the discussion forum next to the study material under discussion.

The particular parallel artifact-centered discourse environment takes from a cognitively active learner the burden of setting up the display by binding a discussion forum and learning material together in one window. This control environment has a twofold purpose in our study. First, as indicated by Van der Pol (2009), the online presence of the learning material may serve as a context for collaboration and strengthen the link between discussion and study material. Second, the software does not assure any coordination between discourse and learning material.

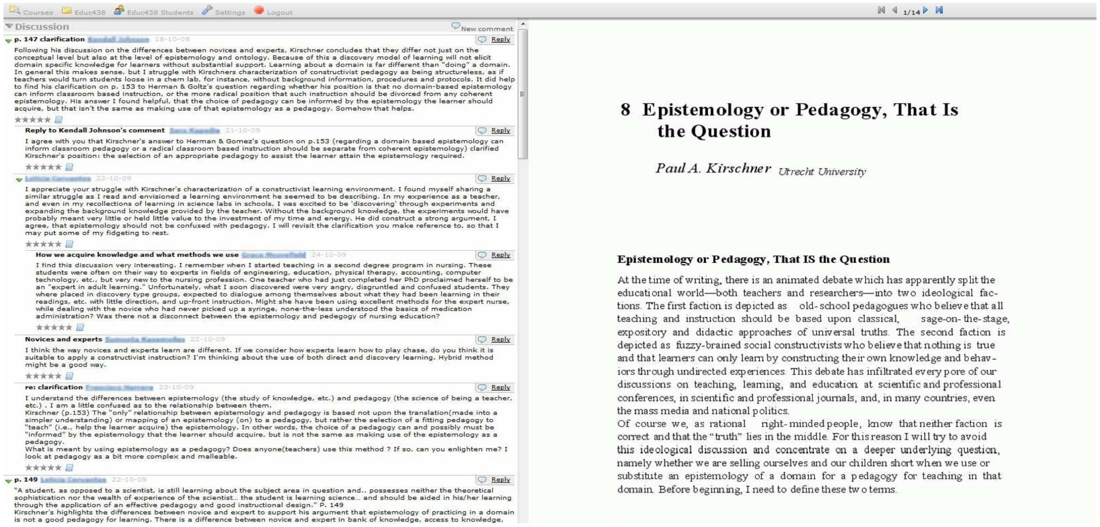


Figure 2. Parallel Artifact-Centered Discourse Environment

Linked Artifact-Centered Discourse Environment

The linked artifact centered discourse environment (Figure 3) displays both discussion and learning material side by side as the control environment, but provides fine-granular links between the two. Van der Pol (2009) referred to this environment as anchored discussion for the notion of contextualized, or "anchored," collaborative discourse within a specific content. The system's design reflects two crucial functions as distinguished by Suthers (2001) to support peer discourse in a shared context. The first function, discussion-to-artifact reference, facilitates establishing a shared frame of reference, as each contribution to discussion is anchored at a specific position (x and y coordinates) in a static document. This medial property may allow the ease of reference, which otherwise would have to be made explicit by linguistic means as in the following example: "I am talking about page three, second paragraph, and line twelve." In addition, selection of a discourse contribution automatically navigates the document to the object discussed by that contribution, disambiguating demonstrative terms such as "this" and "that." The second function, artifact-to-discussion reference, simplifies maintaining discourse coherence by highlighting the chronology of a discussion at a referenced position in a document. This feature may allow quickly grasping and assessing the status of pertinent discourse on an object before making a contribution that will move collaborative knowledge construction forward.

Extensive prior research has compared anchored discussion with a traditional forum discussion (Blackboard) in experimental ways, in order to investigate the quantity and quality of social interaction. These studies showed, for instance, that threads in a system for anchored discussion are significantly longer than those in regular forum discussion (Brush, Bargeron, Grudin, Borning, & Gupta, 2002; Guzdial & Turns, 2000). Other studies found that anchoring discussion leads to a more homogeneous discourse participation (Mühlpfordt & Wessner, 2005) and facilitates expressing complex ideas more easily through shared explicit referencing (Suthers, Girardeau, & Hundhausen, 2003). These results indicate that the interaction-oriented design of an anchored discussion system can be conductive to engage learners in a meaning making process involving articulating, reflecting, and negotiating understanding of an academic text. Building on the metaphor of "common ground" as an internal part of collaborative learning, Van der Pol et al. (2006) demonstrated two effects of the adopted anchored discussion tool compared to regular online discussion. First, they showed that peer discourse in the system for anchored discussion is more oriented towards reconstructing the meaning of the learning material than discussion in a traditional forum, which is more oriented towards the exchange of personal opinions and experiences. Second, they found an increased communicative efficiency due to briefer referrals and messages containing fewer self clarifications than the system for regular forum discussion. Following this argument, Eryilmaz, Alrushiedat, Kasemvilas, Mary, and Van der Pol (2009) demonstrated that anchoring discussion reduced the cognitive load involved in correctly interpreting messages by using MERS (mental effort rating scale) and NASA-TLX (task load index).

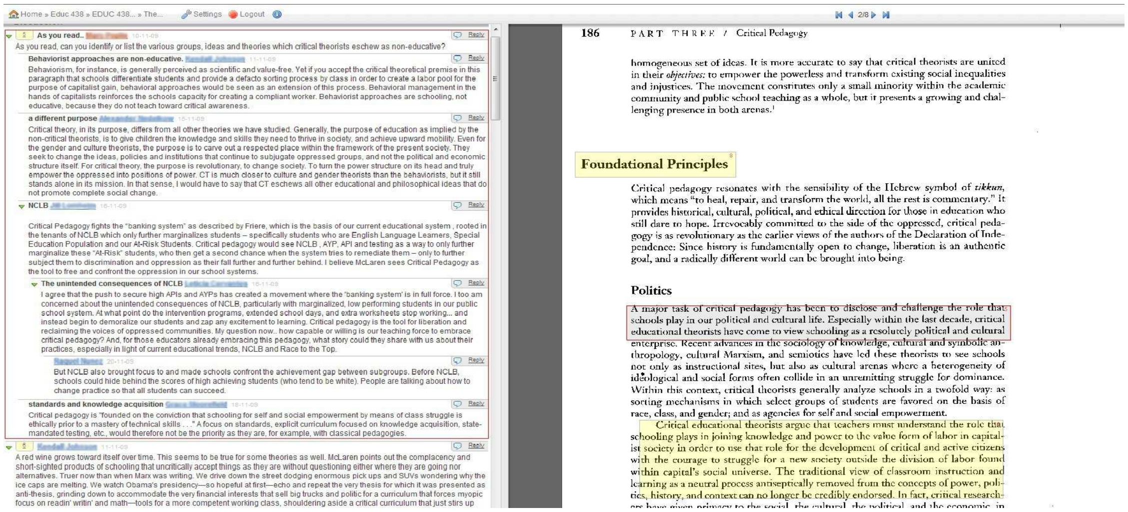


Figure 3. Linked Artifact-Centered Discourse Environment (see www.annotationtool.com/)

While the authors mentioned above determined anchored discussion to be a valuable interaction medium for collaborative learning, they do not directly investigate the effects of anchoring conversation in subject matter per se. By comparing anchored discussion with regular forum discussion, they measure the effects of two functional differences: the presence of learning material on-screen and the possibility to refer to it by annotating. Therefore, as acknowledged by Van der Pol et al. (2006), these studies cannot attribute the found results to either one of these two differences. Therefore, this study examines two forms of artifact-centered discourse environments: one with, and one without the possibility to link, or 'annotate', messages to parts of the learning material. This way, we aim to provide empirical evidence on which previous results can be attributed to the linking functionality and on whether this functionality helps to optimize the division of mental effort between pragmatic grounding and semantic grounding (negotiation) activities in collaborative knowledge construction.

Learning Material

The learning material represents the intrinsic cognitive load that is inherent to the complexity of the learning material being dealt with. Different materials differ in their levels of complexity. It is usually assumed that the natural complexity of the learning material can not be altered by instructional design (Gerjets & Scheiter, 2003). A very high difficulty level may cause students to give up collaborative knowledge construction in frustration. Conversely, a very low difficulty level may not require students to engage in collaboration that mediate their learning. For the scientific objective of this study, learning material difficulty will be kept constant.

Research Model and Hypotheses

The design of a linked artifact-centered discourse environment may reduce students' mental effort to establish and maintain a common ground, which will lead to improved learning results produced by constructive interactions. This study will therefore measure the effect of a linked artifact-centered discourse environment compared with a parallel approach to artifact-centered discourse environment by using the extended research model (see Figure 4) based on prior research. Given this perspective, the central research question is the following: what effect does a linked artifact-centered discourse system have on inquiry-based interaction and learning outcomes?

The major hypothesis of this study is that a properly designed linked artifact-centered discourse system can decrease the mental effort on pragmatic grounding activities, leaving more effort for semantic grounding activities that relate closely to learning. We formulated four sub-hypotheses to test the major hypothesis.

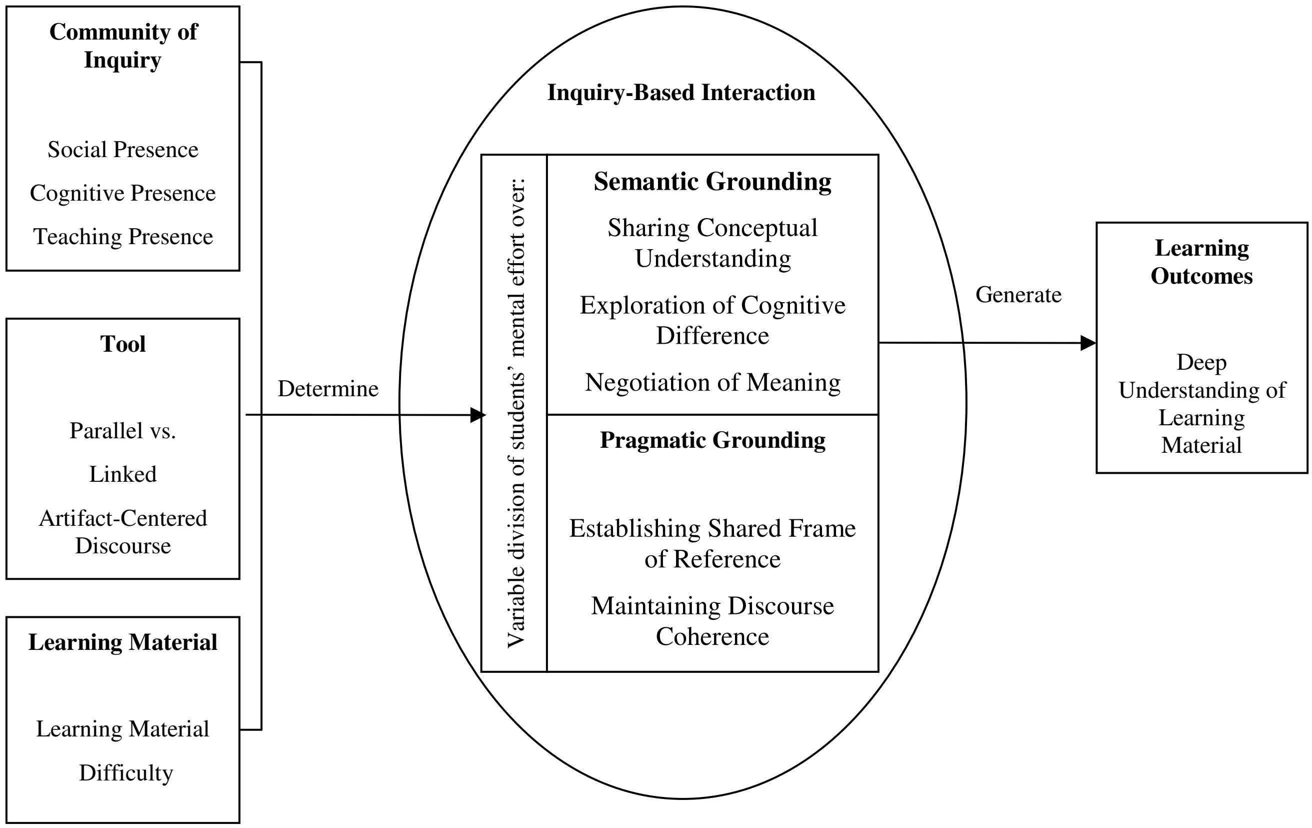


Figure 4. Extended Research Model

H1a. A linked artifact-centered discourse environment will decrease establishing shared frame of reference effort.

By providing the possibility to link messages to specific part of the document, the linked artifact-centered discourse environment should offer conversational threads with a frame of reference that can easily be shared between conversational participants.

H1b. A linked artifact-centered discourse environment will decrease maintaining discourse coherence effort.

The linked artifact-centered discourse environment favors the maintenance of discourse coherence for two reasons. First, contributions about a certain passage are likely not to be as dispersed as in the parallel arrangement, as the 'anchors' in the text will serve to easily organize contributions about the same passage in a single thread, helping to sustain a more focused interaction. In the parallel arrangement, participants will first need to organize "fragmented discourse contributions" (as called by Takeda & Suthers, 2002), before making a contribution that will move collaborative knowledge construction forward. Second, by automatically collecting multiple contributions referencing a given topic, the linked arrangement will retain the chronological development of a particular thread, or "discourse."

H1c. A linked artifact-centered discourse environment will increase semantic grounding effort.

The third sub-hypothesis is motivated by integrating the central tenet of cognitive load theory to social constructivism, which points to a maximum of available mental effort for collaborative knowledge construction. According to this view, we can expect that pragmatic grounding activities facilitated by the linked artifact-centered discourse environment will increase students' mental effort on semantic grounding activities. However, in light of cognitive load theory, Cierniak, Scheiter, and Gerjets (2009) demonstrated that a reduction in interaction costs is not automatically accompanied by constructive interactions. In accordance with Van Merriënboer et al. (2003), we argue that the explicit use of instructional methods may be required to ensure that students devote their freed mental effort to semantic grounding activities. Therefore, the teaching presence component of the research model focuses attention on the didactical part of the learning process.

H1d. Higher semantic grounding effort will increase learning outcomes.

If the linked artifact-centered discourse environment indeed offloads mental effort for pragmatic grounding activities and leaves more effort for semantic grounding activities, then it becomes important and relevant to know the effects of anchored discussion on concrete learning results. We have hypothesized that in particular students' semantic grounding efforts are related to learning and more semantic grounding activities in an inquiry-based interaction should produce better learning effects.

Research Method

The main research followed a quasi-experimental design using a multiple method approach. In preparation for the main part of the study, we conducted an initial pilot with 16 doctoral students registered to a blended format research seminar in learning and pedagogical theories. The pilot study utilized a within group design to observe the change in division of students' mental effort during inquiry-based interaction. The learning materials used in the pilot study were in a domain of educational studies concerned specifically with constructivism and critical pedagogy. The pilot study involved 4 discussions, which served the following purposes. First, it guided the development of the survey questions that measured mental effort spent on establishing a shared frame of reference and maintaining discourse coherence. Second, it familiarized the researchers with the content analysis method and sequential analysis technique that assessed mental effort spent on semantic grounding activities. Finally, it helped the researchers to structure the knowledge pre- and post-tests that determined the individual learning outcomes.

The pilot study shed light on three issues, which we addressed prior to the main research. The first issue was on the parallel artifact-centered discourse environment. Several participants expressed that the software logged them out while they were reading the learning material or a discussion thread. This was a time out problem about user inactivity and we fixed it by changing the idle timeout variable within the software. The second issue was on the internal consistency of the survey questions that measured mental effort spent on establishing a shared frame of reference and maintaining discourse coherence. We re-wrote the questions based on the doctoral students' feedback. The last issue was on the timing of the knowledge pre-test. Due to a conflict in the pilot study course syllabus, we had to give the knowledge pre-test before students read the learning material individually. This was problematic since we could not determine whether learning outcomes were due to social interactions or individual reading. Therefore, in the main research, we gave the knowledge pre-test after students read the learning material individually, but before social interactions mediated by the software environments.

The main research included 106 senior level pharmacy students enrolled in two sections of a clinical pharmacy course. Each group consisted of 53 students. We assigned each section of the particular pharmacy course to either the treatment or the control group. The treatment group students had access to the linked arrangement, whereas the control group students used the parallel arrangement. Thus, all students from one section were in the same condition. We had no reason to expect initial relevant differences between the groups. We assumed prior knowledge concerning physiological healthcare-related topics to be approximately equal for all participants because they all followed the same courses using the same instructional materials in the preceding years. The topics of physiological healthcare focused on fall prevention and geriatrics education. We carried out the main research as a part of a regular curriculum for which asynchronous online discussions, survey questions, and knowledge tests were added to face-to-face class meetings. Prior to online discussions, the instructor taught students the structural components of an argument based on the Toulmin (1958) argumentation framework in approximately three lessons, each averaging about an hour. A different two-week online discussion round covered each learning material. The instructor asked thought-provoking questions specific to the material to be learned at the beginning of the first week and monitored peer discourse. At the end of the first week, when discussions began to reach higher levels of engagement (as in our interaction model), the instructor introduced a second intervening question relevant to the ongoing discourse to provide a direction for collaborative knowledge construction. Some example questions include "what is the author's point of view on the issue?", "is there supporting evidence for the author's conclusions?", and "are those reasons adequate?" The inquiry-based online interaction consisted of 16 discussions in total. We report below the measurement of the variables described in the proposed research model.

Community of Inquiry and Learning Material Difficulty Measurement

We captured the sense of social, cognitive, and teaching presences during inquiry-based interaction through a community of inquiry survey validated by Shea and Bidjerano (2009). Participants provided responses for each question on a five-point Likert type scale ranging from 1: “strongly disagree” to 5 “strongly agree.” For each question, the participants had the option not to answer the question by selecting “N/A.” To determine the difficulty of the learning material, we used a labeled six point Likert type scale with labels ranging from 1 = “not at all” to 6= “extremely.” The learning material difficulty scale asked, “How difficult was the learning material for you?” Because this scale focused on the content to be learned, we assumed that this scale represented the complexity of the learning material being dealt with.

Establishing Shared Frame of Reference Measurement

Establishing a shared frame of reference constitutes the amount of effort a student invests in verbally referencing a contribution to a certain passage from the article and another student’s attempt to access that passage by using the verbal reference provided within that contribution. With respect to referencing a contribution to a certain passage from the article, we used each message as the unit of analysis to get a sense of how each message interacted with the article. We grouped the types of messages into the following categories as defined by the coding scheme developed by Van der Pol et al. (2006): comprehensively referring to a location in the article and demonstratively referring to a location in the article. Referring to a specific location in the article provides information about the amount of contextual information necessary for linking a discussion forum message to the text of the article. On one hand, a long and comprehensive manner involves explicit description of the referent. For instance, “On page fourteen in paragraph two.” On the other hand, a short and demonstrative manner reflects demonstrative referencing such as “here” or “this.” In order to analyze the effort spent on accessing a passage from the article by using the verbal reference provided within a contribution, we developed five survey questions. We revised these questions through the pilot study and then used the revised questions to collect data from the main research.

Maintaining Discourse Coherence Measurement

Maintaining discourse coherence refers to mental effort put into finding conceptually relevant contributions. We developed five survey questions by converting the definition of this construct into a questionnaire format. We then revised these questions based on the pilot study participants’ feedback.

After the completion of the online collaborative knowledge construction task, participants were required to indicate how much mental effort they had invested in establishing a shared frame of reference and maintaining discourse coherence by responding to ten survey questions based on a five-point Likert scale (see Table 1).

Semantic Grounding Measurement

We measured the semantic grounding activities based on content analysis and sequential analysis methods because collaborative knowledge construction in the written communication is a complex phenomenon. For the content analysis, we adopted the coding scheme developed by Pena-Shaff and Nicholls (2004). We used a complete message as the unit of analysis because the previous research of Van der Pol et al. (2006) has shown that messages in the used tool are much shorter than in regular discussions and can generally be regarded as single meaningful units. Also, our coding scheme allowed for multiple different activities to be coded within the same message. Our adopted coding framework consisted of the categories most directly related to the collaborative knowledge construction task presented to the students. These categories are: question, clarification, interpretation, conflict, assertion, consensus building, and support. Question comprises gathering unknown information by starting a discussion or reflecting on a raised problem. It is worth mentioning that clarification used here indicates students paraphrasing themselves and not explaining ideas from earlier in the discussion (see Van der Pol et al., 2006 for a similar approach). Interpretation encompasses inductive and deductive analysis based on facts and premises. A large number of interpretation messages indicate that students are more likely to cover a larger number of viewpoints. Conflict characterizes showing disagreements with information in previous messages. Assertions involve further elaboration of the previously stated ideas. Consensus building reflects effort to attain shared understanding and negotiation to resolve the conflict. Finally, support refers to agreeing with other participants’ contributions.

Although the adopted content analysis method is useful to measure the frequency and percentage of semantic grounding activities, it provides little information on the sequential structure of these activities through which meaning is constructed. Therefore, the main research combined a sequential analysis of interaction with content analysis to shed light on the sequence of semantic grounding activities in peer discourse. The application of such a technique examined how participants accomplished knowledge construction via artifact-centered discourse environments. We carried out a sequential analysis on the coded data by using Jeong's (2003) Discussion Analysis Tool (DAT). The adopted sequential analysis method draws upon the assumption that meaning emerges from the relationship between multiple utterances (or messages) in social interactions. A key implication of this assumption is that meaning does not reside in an isolated utterance. Therefore, sequential relationships of clarification, interpretation, questions, and so forth exist in the essence of understanding how participants collaboratively construct knowledge. DAT operationalizes interaction as two-message sequences (e.g., initial message and response) and offers two metrics for measuring and comparing group interaction patterns: transitional probabilities and mean response scores. DAT calculates transitional probabilities by tallying the frequency of a particular response posted in reply to a particular message type and converting observed frequencies into relative frequencies. DAT is capable of producing transitional state diagrams for a visual illustration of interaction patterns. The second metric, mean response scores, indicates how many times a given type of message is able to produce a specific type of response.

Learning Outcome Measurement

We operationalized the learning outcome variable by using knowledge pre- and post-tests. We conducted the pre-test to examine individual understanding of the theories provided in the learning material after students read it individually but before they discussed it with peers. Thus, the pre-test served to determine prior domain-specific knowledge. Subsequently, the post-test analyzed how much individual understanding improved after peer discourse. An example of a knowledge test question from the pilot study is the following: "Describe the major principles of constructivist learning/pedagogical theory as it related to education." The knowledge tests required each participant to write a reflective essay by working alone for up to 15 minutes. We analyzed participants' essays based on the quality of their argument structuring as well as their ability to provide a balanced and integrated viewpoint (see Jamaludin, Chee, & Mei Lin Ho, 2009 for the reflective essay scoring rubric that was used).

Analysis

We conducted our analysis in three steps. First, we examined whether the perceived community of inquiry and learning material difficulty were the same or different between the groups. Second, we conducted statistical tests to assess students' mental effort over pragmatic and semantic grounding activities during inquiry-based interaction. Finally, we compared the knowledge pre- and post-test scores between the groups to determine the learning outcome.

Community of Inquiry and Learning Material Difficulty Analysis

An independent sample t-test to examine community of inquiry between the groups during online interaction showed no significant differences between the groups ($p > 0.05$). We found no significant difference on perceived learning material difficulty between the treatment group ($M = 3.73$, SD = 0.69, $N = 53$) and the control group ($M = 3.81$, SD = 0.79, $N = 53$), implying that the complexity of the learning material was similar between the groups. This indicates that findings reported below are due to the functional characteristics of the software environments.

Establishing Shared Frame of Reference Analysis

The first sub-hypothesis suggested that the treatment group students would put less mental effort into establishing a shared frame of reference. Specifically, we expected to see differences in the way a student's verbally references a contribution to a certain passage from the article and another student's attempt to access that passage by using the referencing provided within the contribution. To analyze how students referenced their contributions to the text, we categorized messages into two groups: comprehensively referring (e.g. "On page eight in the second to last paragraph") to a location in the article and demonstratively referring (e.g. "While reading this section") to a location in the article. Three coders independently coded all messages. The Cohen's Kappa between Coder 1-2, 2-3, and 1-3 were 0.79, 0.84, and 0.86, respectively for this categorization. Table 1 shows that in the control group we found more comprehensive referrals, $Z = 7.46$, $p < 0.001$, whereas in the treatment group we found more demonstrative referrals, $Z = 5.42$, $p < 0.001$. These findings confirm that treatment group students put less effort into referencing a contribution to a passage from the article.

Table 1. Percentages of Types of Referrals

	Treatment Group	Control Group
Category	Proportion	Proportion
Comprehensive Referring to a Location in the Article	0.01	0.14
Demonstrative Referring to a Location in the Article	0.12	0.03

To evaluate the amount of mental effort students put into accessing a passage by using the reference provided within a contribution, we tested the initial version of the five related questionnaire items with pilot study subjects. The pilot study showed a Cronbach's alpha value of 0.71 for these items. After refinement, establishing shared frame of reference items displayed in Table 2 had an internal consistency of 0.80. An independent sample t-test revealed that treatment group subjects ($M = 2.94$, $SD = 0.53$) invested significantly less mental effort than control group subjects ($M = 3.23$, $SD = 0.41$) for accessing a passage, $t(104) = -3.17$, $p < 0.01$. Thus, H1a was supported.

Table 2. Questionnaire items for Pragmatic Grounding Activities (Ordered in Themes)

Establishing Shared Frame of Reference in Online Discussion
1. "I have been working very hard to find the relevant passage(s) pointed out by my fellow students."
2. "I have been putting a lot of effort into recovering the relevant passage(s) specified by my peers."
3. "I have been really hard working to locate the relevant passage(s) articulated by my group members."
4. "I often had to look for the relevant passage(s) that my peers expressed in their messages."
5. "During the discussion, I was really struggling to detect the relevant passage(s) that my fellow students stated in their messages."
Maintaining Discourse Coherence
6. "I have been putting a lot of effort to find all the messages that concern a particular part of the text."
7. "I have been striving to collect together all messages referencing to a relevant passage."
8. "During the discussion, I was trying very hard to keep track of all the messages concerning with a particular passage."
9. "I have been really struggling to determine the relevant messages on a particular part of the text."
10. "I have been making an intensive effort to find all the messages related to a relevant passage."

All measured as 5-point Likert type items ranging from 1 = "strongly disagree" to 5 = "strongly agree".

Maintaining Discourse Coherence Analysis

The second sub-hypothesis stated that mental effort spent on maintaining discourse coherence would be lower for the treatment group students. We used five related questionnaire items as displayed in Table 2 to test this hypothesis. The initial version of these items had a Cronbach's alpha value of 0.74. The refined items as shown in Table 2 had an internal consistency of 0.84. Consistent with our expectation, treatment group subjects ($M = 3.17$, $SD = 0.53$) put less mental effort into maintaining discourse coherence than did control group subjects ($M = 3.50$, $SD = 0.56$), $t(104) = -3.09$, $p < 0.01$.

Semantic Grounding Analysis

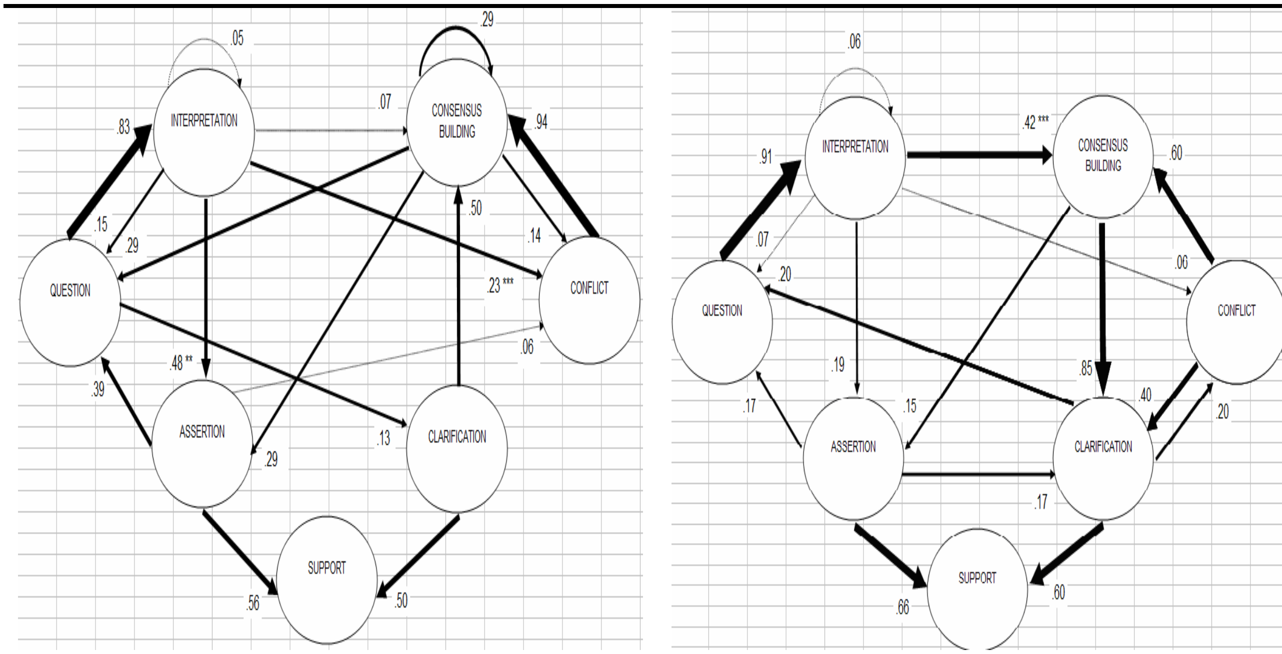
The third sub-hypothesis predicted the semantic grounding effort would be higher for treatment group subjects, compared to control group subjects. Due to the complexity of understanding collaborative knowledge construction in the written communication, we combined content and sequential analyses methods to evaluate this hypothesis. Regarding the content analysis, we were able to identify a total of 995 messages in the discussions for the main study. Three coders received two hours of training in content analysis coding categories and independently coded all messages. The Cohen's Kappa inter-rater reliability figures for the seven categories between Coder 1-2, 2-3, and 1-3 were 0.72, 0.77, and 0.74, respectively, indicating substantial agreement beyond chance. Table 4 presents content analysis results. Interpretations represented almost half of the communication in both groups reflecting that discussions in both groups focused on the meaning of the learning material. There were significantly more clarification messages showing paraphrasing themselves in the control group compared to the treatment group, $Z = 3.99$, $p < 0.001$. While discussions in the control group more often contained support messages, $Z = 2.70$, $p < 0.01$, students in the treatment group seemed to be more apt to identify cognitive differences, $Z = 3.72$, $p < 0.001$. Moreover, there was a higher proportion of assertion messages pointing to further elaboration of previously stated ideas in the treatment group, $Z = 3.48$, $p < 0.001$. Finally, there were no significant differences in the proportions of question and consensus building messages between the treatment and control groups.

Table 4. Content Analysis Findings

	Treatment Group		Control Group	
Category	Number	Proportion	Number	Proportion
Question	82	0.16	77	0.16
Clarification	9	0.02	36	0.07
Interpretation	223	0.45	227	0.46
Conflict	39	0.08	12	0.02
Consensus Building	57	0.11	69	0.14
Assertion	70	0.14	35	0.07
Support	19	0.04	40	0.08
Total	**499**	**100%**	**496**	**100%**

Figure 5 portrays transitional state diagrams to provide a visual birds-eye view of the message-response exchanges in accordance with the coding scheme in Table 4. To ease readability, transitional probabilities less than 0.05 were omitted in the diagrams. On the one hand, the treatment group diagram shows that responses that followed interpretation messages were likely to be assertion or conflict. After detecting a cognitive difference, consensus building was the proffered venue for bridging knowledge gaps, which was then followed by additional consensus building, question, or assertion. On the other hand, the control group diagram shows that interpretation messages were most often followed by consensus building and that consensus building was then followed by clarification. Similarly, both diagrams bring to light that questions inquiring about the learning material generated interpretation messages. Additionally, detection of cognitive differences triggered consensus building. Lastly, assertion and clarification often elicited support.

We analyzed the mean response data to determine to what extent observed differences in interpretation-to-assertion, interpretation-to-conflict, and interpretation-to-consensus building message response sequences are meaningful. We organized the relevant data into Table 5. We found significant differences in the mean number of assertion replies to interpretation messages, $t(448) = 3.17$, $p < 0.01$. Additionally, we found significant differences in the mean number of conflict messages posted in reply to interpretations, $t(448) = 3.50$, $p < 0.001$. Finally, we found a significant transition from interpretation messages to consensus building, $t(448) = 5.23$, $p < 0.001$. Thus, we found support for H1c.



Treatment Group	Control Group

Figure 5. Transitional State Diagrams

Table 5. Message-Response Data

Message-Response Sequences		Treatment Group	Control Group
Interpretation -> Assertion	*M*	0.27 (0.52)	0.13 (0.42)
	N	223	227
Interpretation -> Conflict	*M*	0.13 (0.34)	0.04 (0.20)
	N	223	227
Interpretation -> Consensus Building	*M*	0.04 (0.22)	0.27 (0.61)
	N	223	227

Note. Standard deviation in parenthesis.

Learning Outcome Analysis

The last sub-hypothesis implied that more constructive interactions would produce a deeper understanding of the learning material. The maximum possible score for the pre-test and the post-test was 12. The mean scores on the pre-test were 5.66 (SD = 1.36) and 5.71 (SD = 1.46) in treatment and control groups, respectively. An independent sample t-test revealed no significant pre-test differences between the groups ($p > 0.05$). In order to measure knowledge acquisition, we computed a gain in knowledge score for each student (post-test score minus pre-test score). The mean score in the treatment group (M = 2.23, SD = 1.10) was noticeably greater than that in the control group (M = 1.55, SD = 0.89), $t(104) = 3.33$, $p < 0.01$. This finding provides support for H1d.

Results

Based on the proposed research model, we tested four sub-hypotheses to examine the merits of a linking functionality on inquiry-based interaction and learning outcomes. We now discuss the hypotheses findings. The first sub-hypothesis predicted that a linked artifact-centered discourse environment would decrease establishing a shared frame of reference effort. Two lines of evidence support this sub-hypothesis, based on content analysis and questionnaire data. First, content analysis data clearly shows briefer referrals (demonstrative rather than comprehensive) in the linked arrangement which indicates that treatment group students invested less mental effort in verbally referring to parts of the article during message construction. Second, the questionnaire items focusing on establishing a shared frame of reference demonstrate that the recipients of a message in the treatment group did not actively search for the intended reference. In accordance with Eryilmaz et al. (2009), these findings suggest that relating a message to a shared context is an effective way of clarifying its meaning. These findings are important because they highlight that the discussion-to-artifact design principle, as distinguished by Suthers (2001), decreased the mental effort required to create a shared frame of reference.

The second sub-hypothesis predicted that a linked artifact-centered discourse environment would decrease maintaining discourse coherence effort. Questionnaire items for maintaining discourse coherence provide evidence that maintaining discourse coherence was easier with the linked software arrangement. Moreover, higher proportion of clarification messages reflecting students paraphrasing themselves in the discussion for the parallel arrangement software points to an insufficient degree of understanding about the meaning of utterances during conversation. It can be assumed, therefore, that these messages carried the cost of repairing the misunderstandings for collaboration in verbal interactions. This finding corroborates the difficulty of maintaining discourse coherence for the control group participants. This beneficial effect for maintaining discourse coherence is consistent with the postulation of Takeda and Suthers (2002) and confirms that getting a sense of the whole discussion or noticing relevant relationships between different parts of the text was easier with the linked software arrangement. We attribute this finding to the artifact-to-discussion design principle as distinguished by Suthers (2001).

The third sub-hypothesis predicted that a linked artifact-centered discourse environment would increase semantic grounding effort. The coding results from the transcripts make evident that interpreting the meaning of the learning material constituted nearly half of the messages in both software environments. In accordance with Dillenbourg et al. (1996), this finding shows that students in both groups had different perspectives about the topic under discussion, which is fruitful for collaborative knowledge construction. We attribute this finding to the online presence of the learning material and thus support Van der Pol et al.'s (2006) postulation that the on-screen presence of the article orients students' contributions towards reconstructing the meaning of the learning material. Furthermore, the coding results from the transcripts confirm previous findings that a linked artifact-centered discussion offers less evaluative and more constructive forms of collaboration, when used for collaborative literature processing (Van der Pol et al., 2006) or interactive peer feedback (Van der Pol, Van der Berg, Admiraal, & Simons, 2008). The current results, however, go beyond those previous insights, as they show us what these more evaluative collaboration patterns look like and provide insight into why these may be less productive for learning. As we have seen, the consensus building pattern in the control condition showed significantly more transitions from interpretations to consensus building messages, whereas the experimental condition showed more transitions from interpretation to assertion and conflict, meaning that students put more effort into processing of the subject matter and collaboratively increasing understanding of it. A possible important reason underlying these results may be that constructing new understanding of the subject matter through a process of elaborative and argumentative activities takes more effort then consensus building conversation.

The last sub-hypothesis predicted that higher semantic grounding effort would increase the learning outcomes. Gain in knowledge scores between students' pre- and post-test essays provide evidence that the treatment group students acquired deeper knowledge and patterns of reasoning than did those in the control group, implying that some discussions lead to more effective learning than others. This result supports the findings of Pfister and Mühlpfordt (2002) that discussions structured with a linking functionality lead to deeper learning by illustrating the learning potential of specific interaction processes.

Conclusion

In this paper, we proposed a research model for a better understanding of the relation between inquiry-based interaction and learning outcomes. The theoretical foundation of the research model combined social constructivism, grounding theory, and cognitive load theory. The proposed model attempts to illustrate that pragmatic grounding activities form the bottom layer for semantic grounding activities, which directly relate to learning outcomes. In order to evaluate the proposed model, we conducted a quasi experimental design with two forms of artifact-centered discourse environments. Overall, we found strong empirical support for our model. Foremost, our results demonstrated that the linking functionality in an artifact-centered discourse environment facilitates pragmatic grounding activities to attain a common ground. This result is particularly salient in inquiry-based interaction because collaborative situations require the coordination and regulation of the social interaction process itself. This proved to be a pressing problem in the parallel artifact-centered discourse environment. Especially, the control group students' remarks on paraphrasing themselves signaled the loss of a common ground. Second, our results showed that less need to attain an adequate level of common ground through pragmatic grounding activities indeed left more room for semantic grounding activities in inquiry-based interaction. This result implies that facilitating pragmatic grounding activities have positive influence on semantic grounding activities. Relating this result to an "interactionist" view (Suthers, 2006), we can now state that attaining a common ground is a viable way towards more complex forms of social interactions focusing on a text. Finally, our results indicated that more semantic grounding activities lead to a deeper understanding of the learning material. This returns us to the core theoretical issue motivating the current paper that not all mental effort is good for collaborative learning situations. In response to this core theoretical issue, the experimental results present compelling evidence that the ultimate learning value of a peer discourse depends on the semantic grounding activities.

These results have important implications for instruction. As we have shown, parallel and linked artifact-centered discourse environments provoked students to take a stance on the primary text and sustain a topic related discussion. This implies that setting up an artifact as the topic of an asynchronous online discussion may set students' collaborative intentions towards constructing the meaning of a text. Thus, the parallel software arrangement may typically be useful for a sustained general on-topic discussion. However, if the instructional intention of an online discussion is to allow students consider different perspectives and build on each other's comments, then the parallel software arrangement is insufficient due to the issue of attaining a common ground. A central insight of our study is that a linked software arrangement provided a worthy solution to the issue of attaining a common ground in online learning conversations.

We are aware that typical tools for online learning conversations (such as Blackboard) display the artifact and the associated discussion in separate windows. Instructors interested in using an artifact-centered discourse environment can work around this problem in several ways. One way is to use the free linked artifact-centered discourse environment adopted in this study. Another way, as suggested by Suthers (2001), is to open two windows and place the discussion forum next to the study material. A third option may involve direct instruction and have students quote the relevant parts of the text as they type a message.

We fully acknowledge that our findings are limited to the specialized doctoral students in educational studies and senior level pharmacy students. This encourages future research to replicate the current study with more undergraduate and masters level students. But, it is worth noting that the specialized students may need specialized tools more than undergraduate and masters level students. We will continue to examine whether a higher degree of common ground decreases pragmatic grounding activities during conversation as pointed out by Van der Pol (2009). We would like put forward two worthy avenues for future research. First, we seek to guide the target of students' annotations based on the relative importance of each sentence in a text. Second, we aim to assist students with their inquiry skills by integrating the elements of Toulmin's (1958) argumentation framework to the linked-artifact centered discourse system.

Acknowledgements

The authors would like to thank to the anonymous reviewers for their constructive comments on the early version of the paper. The first author also expresses his gratitude to Katherine Veach for her helpful comments about the readability of the paper.

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