Knowledge Creation Analytics for Jigsaw Instruction: Temporal Socio-Semantic Network Analysis

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Abstract: This study aims to gain insight into how to design lesson plans with jigsaw instruction to promote knowledge creation. Collaborative learning has been discussed as a method for improving students' learning. However, little research on jigsaw instruction analyzed from the knowledge creation perspective has been conducted. Previous research has resulted in the development of the new temporal socio-semantic network analytics (SSNA) to emphasize the visualization of ideas changing during the knowledge creation process. Therefore, we conducted temporal analysis on students' learning of a more complex problem through jigsaw instruction than previous studies to examine the differences between high- and low-learning-outcome groups. The results of three investigations suggest that designing lessons such that they prompt students to engage in generative tasks can contribute to learning as knowledge creation.

Theoretical background and research purpose

In the learning sciences, collaborative learning has been discussed as a method for facilitating learners' deeper disciplinary knowledge. Among the many types of collaborative learning, jigsaw instruction is a method that has been examined in many studies (Miyake & Kirschner, 2014). Jigsaw instruction is comprised of two participatory structures of collaborative learning: expert group activity and jigsaw group activity. In expert group activities, learners in a group are given the same material to study collaboratively. Conversely, in jigsaw group activities, each learner provides others with new information and knowledge obtained during the expert group activity.

While most studies on jigsaw instruction have analyzed collaborative learning as knowledge integration in the belief mode (Bereiter & Scardamalia, 2003), few studies have examined how learners' attempts to improve their ideas as collaborative knowledge objects in the design mode from the knowledge creation perspective. In the knowledge creation metaphor of learning (Paavola & Hakkarainen, 2005), learners are assumed to practice knowledge creation by collaboratively constructing knowledge objects (Scardamalia & Bereiter, 2014). In previous research on the jigsaw instruction method from the aspect of knowledge creation, the results have suggested that students should engage in creating knowledge objects, and educators should design embodied learning in class through design-based research (Oshima et al., 2017). However, no studies have tried to discuss how to design elements of jigsaw instruction from the perspective of knowledge creation.

Evaluating learning as knowledge creation practice is challenging because it involves the collective nature of knowledge. The primary target in knowledge creation is the collective state of knowledge constructed by a community of learners, and to evaluate collective knowledge advancement in knowledge creation practices, it is necessary to develop analytics answering the following questions: (1) how is the collective nature of knowledge is represented, and (2) how is dynamic change represented over time (Scardamalia & Bereiter, 2014)? The socio-semantic network analysis (SSNA) of discourse has been discussed as a promising approach for answering these questions (Oshima et al., 2012). As an application of SSNA, KBDeX represents the collective nature of knowledge as clusters of words representing ideas used in discourse and visualizes how a word's network structure changes over time. KBDeX also calculates several metrics, such as degree centralities, for network structures. Previous studies (Oshima et al., 2017; 2018) have demonstrated how different high- and low-learning-outcome groups engage in their collaborative discourse in a jigsaw group activity to discuss future instructional interventions to support low-learning-outcome groups.

There have been critical developments in the SSNA algorithm since the first presentation of SSNA as a knowledge creation analytic for jigsaw instruction (Oshima et al., 2017). Recently, Ohsaki and Oshima (2021) developed a new algorithm by applying the lifetime connection between words in a network and the real-time scale in visualizing the trajectory of metrics over time based on studies in dialogism and network science. Their study revealed that temporal network analysis is more appropriate for finding critical points in the discourse for idea improvement than aggregative network analysis.

In this study, based on the developments in the SSNA algorithm in recent years, we examine how discourse in knowledge creation practice is related to learning outcomes to gain insights into how jigsaw instruction design can be improved with further instructional support. We approach the research purpose with the following research question: how does the engagement of students in the high-learning-outcome group in the discourse differ from that of students in the low-learning-outcome group?

Method

Data collection and study design

We used a dataset with undergraduate students' pre-tests, post-tests, and collaborative discourse in a jigsaw group activity collected during a lesson unit that was part of a course on science education. A group of primarily second-year students created presentations on an air conditioner's mechanism as a complex problem that integrated science, technology, and engineering knowledge. A total of 29 students from the biology and environment departments were divided into nine groups of three or four. The main challenge of the jigsaw activity was, "How does an air conditioner continue cooling a room?" In the expert group activity, each member studied the three different documents on (A) theory of heat, (B) phase change and thermal energy, and (C) pressure and temperature in a different group for about 20 min. Next, members from different groups created a new group for the jigsaw group activity. Then, groups took on the main challenge by creating a presentation over 24 min.

We designed this study based on previous research (Oshima et al., 2017). Before and after the lesson unit, a teacher conducted pre- and post-tests to evaluate individual learning outcomes by using a worksheet with the main challenge printed as a question. A total of 28 students completed both tests by writing or drawing their ideas. Moreover, students' conversations during expert and jigsaw group activities were video-recorded. We transcribed discourses in the jigsaw group activity to examine how students engaged in collaborative problem-solving techniques. There was an average of 260.22 (SD = 70.66) utterances.

Analysis

To examine the research question, we conducted three investigations based on Oshima et al. (2017; 2018). The first investigation defined the high-learning-outcome group as one in which all students integrated knowledge from learning resources. We analyzed students' writing and drawing on the pre- and post-tests by plotting their understanding of an air conditioner system based on the Structure-Behavior-Function (SBF) framework (Hmelo-Silver & Pfeffer, 2004). Students were divided into four categories from "no understanding" to "fully integrated understanding across three documents" using the same categories as Oshima et al. (2017). When students' explanations in pre- and post-tests considered the relationship among structures, behaviors, and functions described in learning resources, we concluded they successfully understood the document. The first author and a trained student belonging to the laboratory for learning sciences independently evaluated students' SBF frameworks based on their explanations in each pre- and post-test. In this evaluation, Cohen's Kappa coefficient for the agreement between the two raters was 0.97. Disagreements were resolved through discussion.

The second investigation analyzed students' collective knowledge advancement through discourse analysis using temporal SSNA (Ohsaki & Oshima, 2021) to visualize students' knowledge advancement transitions and define the pivotal points for in-depth dialogical analysis. We selected 28 terms to explain the main challenge by a teacher, keywords in the learning resources, and basic scientific terms. KBDeX calculated the transition in the total value of the degree centralities of terms as nodes in the network across discourse exchanges. Additionally, we divided the lesson into three phases to analyze this visualization in detail.

The third investigation was an in-depth dialogical analysis to assess how students acted with collaborative problem-solving mechanisms. We chose the results from the most active group from each category and analyzed their discourse data at the defined pivotal points in three phases of the lesson. This method was based on the hypothesis that a stage near the highest degree of centrality would display the characteristic activity.

Results

From the investigations, we confirmed that four groups had integrated SBF understanding. These four groups were the high-learning-outcome groups, and the other five groups were the low-learning-outcome groups. The individual analysis results showed that 10 students were fully integrated, 13 were partly integrated, five expressed a single understanding of the learning document, and none were in the no-understanding category. Chi-squared analysis of student frequencies across high- and low-outcome-groups (fully or partially integrated and the single document) showed significance ($\chi^2 = 31.36$, $df = 2$, $p < .01$).

In the second investigation, the transitions in the total values of the degree centralities in each group showed a striking difference between the high- and low-outcome groups regarding whether to maintain the word clusters' changes (Fig. 1). The images' vertical axes signify the degree centralities' absolute values, and the horizontal axes represent time. The lines for the high-outcome groups illustrate that students continually used keywords and tried to connect these keywords to various teams. This difference is especially evident in the late phase of the lesson. The low-5 group peaked at the end of the first phase and was slightly different from other low-outcome groups, but the change in the second phase is not shown in Fig. 1.

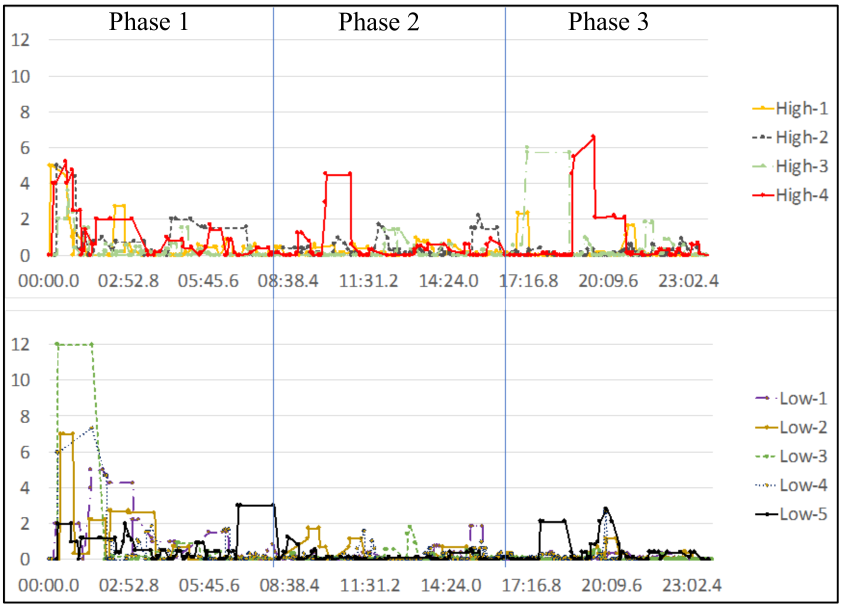

Figure 1. The transitions in the degree centralities of the high-learning-outcome groups (upper) and low-learning-outcome groups (bottom).

Dialogical analysis in the third investigation showed details in the differences between the high- and low-outcome groups. For this analysis, we chose groups high-4 and low-5. Next, we focused on pivotal points in each phase that were the highest for both groups because they show the group activities' characteristics. The first pivotal point for the high-outcome group confirmed that at 37 s, students shared knowledge from the documents. Then, they shared knowledge until the early timing (2 min 59 s) in phase 2, which is the second pivotal point. The pivotal point in phase 3 for the high-outcome group was at 19 min 38 s. By preparing the presentation, students checked their understanding. The original discourse data was in Japanese and was translated into English by the first author (keywords in SSNA are shown in italics). The discourse around the first pivotal point was as follows.

Student 4A (#5):	In this document, *heat* moves from the high-temperature side to the low-temperature side, but it does not transfer from the low-temperature side to the high-temperature side. This is a physics explanation… *the second law of thermodynamics*. So, *thermal energy* moving with the material is called the *refrigerant*. It seems that a *refrigerant* carries *heat*.
Student 4C (#6):	Hmm. *Refrigerant*….
Student 4A (#7):	Right, so, yeah, at this… at this point, in the *condensation* and *evaporation* units, *thermal energy* moves between a *refrigerant* and the air.
Student 4C (#8):	Hmm, hmm, hmm.
Student 4A (#9):	This is the mechanism. Right. A *heat pump* mechanism transfers *thermal energy* from a cold space to a warmer one because of external *power*. It is similar to *an air conditioner*.

Even though, from Phase 1, the students in the low-outcome group started sharing the knowledge that they gained from the documents, the first highest point was marked when changing phases from 1 to 2 (around 6 min 52 s). At this point, they tried to learn the contents of document B because they had not engaged in sharing prior. Then, at the second pivotal point (8 min 34 s), dialogue data showed that students had tried to integrate knowledge collected from the documents. The low-outcome group's last pivotal point was shown at 19 min 58 s; it was close to the last high-outcome group's pivotal point. The students then discussed their understanding.

Discussion

This study's purpose is to improve the design of jigsaw instruction with further instructional support. Accordingly, this study raised the research question: how does the engagement of students in the high-learning-outcome group in the discourse differ from that of students in the low-learning-outcome group? The answer to this question can be discussed based on the shape of the graph in Fig. 1. The temporal SSNA delineated the high-outcome group's characteristic as a frequent shape consisting of a higher and lower score through all phases. Meanwhile, the transitions in the low-outcome groups' lines tended to both show the most dynamic changes at first and then relatively little change later. In addition, there were differences between the high- and low-outcome groups both in the value of the total degree centralities and the timing of change. Furthermore, it is suspected that the high-outcome group's members tried to create a common understanding based on other members' information from phase 1. This is because the line for high-4 in Fig. 1 delineates that they shared the documents' contents and mentioned many keywords during the first phase. The importance of creating a shared understanding has been discussed in previous studies (Oshima et al., 2017; Damşa et al., 2010). Additionally, moving to the stage of re-creating knowledge objects (namely, "generative collaborative actions") (Damşa et al., 2010) can also be attributed to the creation of shared objects from the early phase. Consequently, the present study suggests that epistemic goals and activity time are important in supporting low-outcome groups.

These findings suggest that when teachers support students to engage in a generative task, students may be more likely to engage in learning as knowledge creation. The low-outcome groups in the dataset could not engage in generative collaborative actions. Thus, redesigning the main challenge for smooth transitions to the generative task might prompt students to create a shared understanding and transition to generative collaborative actions. One possible main challenge may be to ask students "please explain why vending machines with heat pump systems are good for the earth." To solve this task, they need not only to integrate their knowledge but to generate their own idea based on knowledge from learning resources on an air conditioner as a heat pump system. This study contributed to the further development of jigsaw instruction as collaborative learning designs from the knowledge creation perspective, but it just analyzed a single case. In future studies, the hypothesis detected in this study should be examined by analyzing more data.

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