Analytics for Creative Practice from Knowledge Building Perspectives: The combination of temporal socio-semantic network analysis and ordered network analysis

Abstract: This study applied a new analysis method from the knowledge-building perspective and examines the differences in creative practice between engineers and designers. As a type of creative practice, many classrooms have design activities recently. Moreover, in the computer-supported collaborative learning (CSCL) field, analytical and supporting methods for creative practices have been examined. In this study, we analyzed the discourse data in short prototyping by professional designers and engineers using the combination of temporal socio-semantic network analysis (tSSNA) and ordered network analysis (ONA), which are advanced methods for knowledge-building discourse. Accordingly, we confirmed that (1) both teams kept changing ideas until the end of activities, (2) their working processes for the design actions in the epistemic frame were similar, and (3) their actions in the shared epistemic agency were slightly different. This study suggests the importance of data analytics based on two perspectives: idea improvement and epistemic agency, for knowledge-building practices.

Background and research purpose

How to analyze creative practice, such as design activities in the maker space and knowledge-building practices, to support learners is one of the important topics in computer-supported collaborative learning (CSCL) (e.g., Kajamaa & Kumpulainen, 2020; Oshima et al., 2022). In the analysis of discourse data for knowledge building, which is a learning theory of the knowledge creation metaphor, it is necessary to analyze two perspectives: idea improvement and epistemic agency. Oshima et al. (2020) developed a double-layered analysis including those two perspectives by combining socio-semantic network analysis (SSNA) (Oshima et al., 2012) and epistemic network analysis (ENA) (Shaffer, 2017). After this study, both analytical methods for idea improvement and epistemic agency were advanced as temporal SSNA (tSSNA) (Ohsaki & Oshima, 2019; 2021a; 2021b) and ordered network analysis (ONA) (Tan et al., 2022). It is known that analytics without temporality might produce misleading data analyses (Ohsaki & Oshima, 2019; 2021a). Furthermore, ONA (Tan et al., 2022) can illustrate the directions of participants' epistemic frames, which ENA does not include. Therefore, in this study, we use tSSNA and ONA to find out more about what previous study hadn't done.

From the contextual perspective, this study describes the ideal activities by analyzing data on engineers' and designers' creative practices because they will serve as a guide for supporting learners. Although knowledge building is based on the activities of scientists, designers, and engineers, few studies have analyzed professional work (Chen & Hong, 2016; Scardamalia & Bereiter, 2014). Ohsaki and Oshima (2022) analyzed the data of engineers and designers through the previous double-layered analysis created from the knowledge-building perspective. Accordingly, they showed that the engineering and design teams had different epistemic frames even though both teams continued changing ideas at the end of practice. However, that study used the previous double-layered analysis created from the knowledge-building perspective by Oshima et al. (2020). Hence, we analyze the engineers' and designers' data using a new double-layered network analysis with advanced SSNA with temporality and ONA. In addition, Ohsaki and Oshima's study (2022) used the data of designers with less experience, which might have affected the results. Consequently, the present study analyzed the updated engineers' data and new designers' data in the short prototyping process, which could be done in one lesson, using a new analytical method.

This study poses two research questions: (1) How can the combined tSSNA and ONA methods visualize the activities of engineers and designers as they engage in knowledge-building practices? and (2) What are the differences among idea-changing, shared epistemic agency, and design actions between the engineering team and the design team in the short prototyping process?

Methods

To examine the research questions mentioned above, we conducted the tSSNA and ONA, analyzing the data of the short prototyping process as creative practices by designers and engineers. First, from the perspective of idea improvement, we defined phases through the tSSNA analysis. Second, we modeled the epistemic framework of students using ONA. Lastly, we presented representative qualitative examples from the discourse data to demonstrate participants' engagement in knowledge-building practices.

Data

The dataset was collected for two cases of knowledge-building practices. The task participants worked on was to design and create a new wallet based on specific user needs. This was a timed task and challenge was not open before the practice and all participants should solve the task for the same users during similar time period. This practice had two sessions in one hour and half. First, the participants planned a three-day project as a scheduling session for an hour. Second, the participants did prototyping for 30-min as the first step of their plan. The participants were embroiled for creating new educational material in the university and this practice was part of their work. They understood that their outcomes in this practice would be used as a good example for educational programs for design, engineering, and HCD and required sample of their product or service and a presentation video as final outcomes. The honorarium was decided by their current positions.

This study analyzed the data of engineering team and design team. These practices were recorded and transcribed to discourse data. The discourse data comprised 325 lines for the engineering team, and 585 lines for the design team. In the engineering team, three engineers participated in the practice. They were also students at a professional graduate school in software engineering. Two of them had many experiences as engineers and were interested in the prototyping method. Another one was young, but this participant studied and worked software engineering hard. Hence, these three members were deemed appropriate for the work. In this team, their final product was the wallet for abroad. They focused on that the user wanted the wallet abroad and the user was a woman. The characteristic points of their product ware a chain and anti-skimming sheet to protect the wallet from thieves. Also, the appearance design theme was colorful and cute. The design team was constructed of three service designers. All of members had designed service in business field and these three members were deemed appropriate for the work. The design team proposed that the brock-based wallet with good touch because the user had a wallet with soft touch and this parson wanted slim wallet.

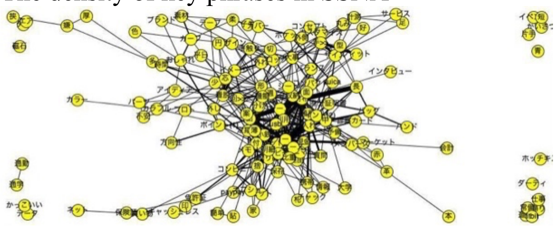
Analytics for idea changing

This study used tSSNA to capture idea changing. tSSNA is an analytics method that adds the concept of network lifetime and the moving stanza window method to SSNA and uses data with timestamp information (Ohsaki & Oshima, 2019; 2021a). SSNA, a well-known analytics method of idea improvement in knowledge-building research (Chen et al., 2015; Oshima et al., 2012; Scardamalia & Bereiter, 2014; 2022), creates a network using key terms as nodes (Figure 1). The total value of degree centrality (TDC), which shows the density of key phrases, describes how ideas change. For details on the calculation by SSNA, please see Oshima et al. (2012).

There are three advantages of tSSNA. First, it can show the similarities and differences in idea changes in a classroom on the same time scale. For example, Ohsaki and Oshima (2021a) illustrated that the students' activities in both high- and low-outcome groups were revitalized by the teacher's announcement of the time limit. This situation was not shown in the previous SSNA because they did not use timestamp data. The second advantage of tSSNA is emphasizing the change in TDC values using the moving stanza window method (Ohsaki & Oshima, 2019). Finally, the third beneficial point of tSSNA is that the concept of network lifetime contributes to showing how students treat ideas in practice. For example, tSSNA illustrates trapezoidal graphs when students discuss the same ideas for a while (Ohsaki & Oshima, 2021a).

Figure 1

The density of key phrases in SSNA



Analytics for epistemic agency

For analyzing epistemic agency, this study used ONA, an analytical method that implements directionality in ENA to consider the order of human actions (Tan et al., 2022). ONA constructs directed network models of collaborative learning by accounting for not only the interactive, interdependent, and temporal nature of collaborations, but also the temporal order of events in collaborative processes (Tan et al., 2022). ONA can model the order of events in collaboration by tracking both what units of analysis respond with and what they respond to as they interact with others in the team and can represent such connections in directed network models. The directionality of actions in discourse is meaningful to support learning. This is because it allows confirmation of what actions lead to important actions based on their directionality. Besides, this information helps to design lessons, educational materials, and facilitation.

The directed connections in ONA are represented by edges between nodes, visualizing as a pair of triangles. Note that unlike most ordered network visualizations, which use arrows or spearheads to indicate directionality, ONA uses a "broadcast" model, where the source of a connection (ground) is placed at the apex of the triangle and the destination of a connection (response) is placed at its base. To facilitate interpretation, the dark chevrons place inside the triangles indicates the directionality of the connection from ground to response.

Coding

For analyzing epistemic agency, this study used two coding tables: design actions from the creative practice framework and shared epistemic agency (Damşa et al., 2010). The data was coded through social moderation where two raters discussed and resolved differences in coding after both of them coded the same data independently (Herrenkohl & Cornelius, 2013).

The first coding table (Table 1) was created by two theories. The first design theory was design thinking (Brown, 2006), which is perhaps the most popular design model. This design process model is based on the concept of human-centered design and suggests starting with a user interview. On the other hand, the second design theory, innovation of meaning (Verganti, 2017), suggests starting with an individual designer's vision. The two design theories suggest different processes, but they do not differ in their emphasis on prototyping. Hence, the coding table was constructed to contain five categories (User, Vision, Prototype, Functions, and Aesthetics) by adding Functions and Aesthetics as design targets. This coding table was an updated version of that in Ohsaki and Oshima (2022).

Table 1
The coding table for design actions

Category	Definition	Example
User	Talking to/about a user *Including the user talks answer to interview.	Is there anything you think is missing from your current wallet?
Vision	Talking about individual vision or evaluating/deciding shared idea	But I feel like I don't see much navy blue. Do you?
Prototype	Talking about prototype	We can create pockets by pasting on these [materials].
Functions	Talking about the product/service functions.	This wallet can be used overseas, so it has skimming protection.
Aesthetics	Talking about visual/fitting design	Uh, leather. White, black.

The second coding table of the shared epistemic agency was used in the previous studies for knowledge-building practices (Oshima et al., 2019; 2020). The framework is constructed by knowledge- and process-related dimensions and seven categories (Damşa et al., 2010). Table 2 shows the coding categories, definition, and example utterances for the shared epistemic agency.

Table 2
The coding table for shared epistemic agency (Damşa et al., 2010; Ohsaki and Oshima, 2022)

Category	Definition	Example
Creating awareness (CA)	Pointing out what is missing	Is there a difference between wallets used in Japan and those used overseas?
Alleviating lack of knowledge (ALoK)	Trying to acquire missing knowledge and criticizing the information source	By the way, why did you choose the current wallet?
Creating shared understanding (CSU)	Bringing up their knowledge and checking another person's understanding to create a knowledge object	Thin is also good, right? Minimalist-like...
Generative collective actions (GCA)	Improving the created knowledge object	Additionally, we can extend the functionality of this wallet by...

Projective	Planning activities for a goal	We have about 10 minutes left.
Regulative	Monitoring the object created by the participants	This [prototype] is fine [for us].
Relational	Giving other members space for contribution.	Oh, that's nice. Let me see your wallet.

Results

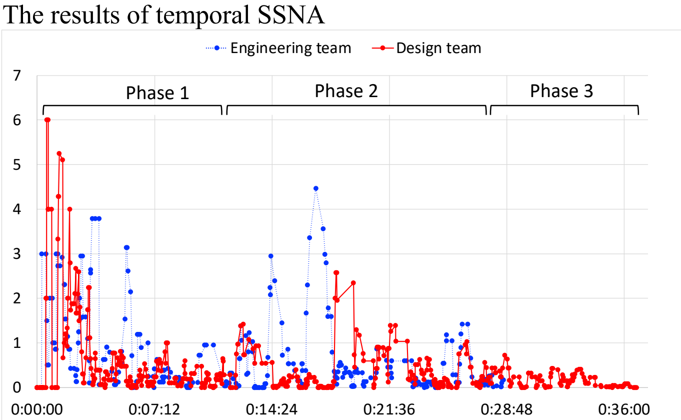
Analytics for idea changing

The results of the first analysis are for idea changing, as shown in Figure 2. The y-axes in the graphs show the TDC, while the x-axes show the timestamps of the discourse from the start of the prototyping session. Overall, both teams continued to change their ideas until the endpoints. Those activities are the same as the ideal knowledge-building practice principle (Scardamalia & Bereiter, 2022). When we focused on the pattern of the TDC, both teams had high scores and frequent vibration of TDC scores at first. Later, the shape of the changing score showed a temporary decrease and then recovered to a high variability and score. Finally, the values of the score decreased, but the variability of TDC still remained.

Based on these results, we divided the group activities into three phases. To seek division points, we defined potential division areas based on the graph and confirmed the specific scores around the potential division areas. Furthermore, we used the concept of a topic-changing point in SSNA based on Barany et al. (2021). Their study set up the topic-changing point when the TDC score decayed twice in a row.

The first phase was from the starting point to approximately 10 minutes beyond; in this phase, both teams scored a high TDC. Both teams had interviews with the user in this phase. Generally, in the early stage of DT, the designers have user interviews. Participants in the practice are considered to have followed this method. To seek user needs, participants used various key terms during this phase, similar to networks that also have many key terms. The second phase was from approximately 10 minutes to approximately 27 minutes. The TDC score line in this phase has some trapezoidal shapes. This result indicates that the teams continued conversing with key terms. Furthermore, there are some places where the scores of TDC suddenly rise, showing that they talked about their product or service using a variety of key terms. The third phase extends from approximately 27 minutes to the endpoint. Once again, both teams continued to change their ideas until the endpoints. The engineering team was satisfied with their results and stopped prototyping at approximately 28 minutes. Therefore, the length of the discourse data in the final phase was approximately 2 minutes. In the design team, the TDC score did not change in the last few minutes. However, this is because they performed prototyping until approximately 35 minutes point and concentrated on creating prototypes instead of having discussions.

Figure 2
The results of temporal SSNA



Analytics for epistemic agency

The ONA graphs in each phase present the characteristics of how participants engaged in design actions during the three patterns of idea improvement. This study used two coding tables for analysis from the epistemic frame perspective, as described in the Methods section. The first codes were for the design actions (Table 1). The upper graphs in Table 3 presents subtracted graph for participants' design actions in each phase. Prototyping and User were placed contrastingly on the left and right in the graph, respectively, while Aesthetics and Functions and were placed contrastively on the top and bottom, respectively. Overall, the characteristics of engineers (blue) were self-connections of User and Prototyping. Moreover, the connection between Aesthetics and Prototyping is a pinch point in the middle, representing how the engineer considered aesthetics design while creating the prototype. On the other hand, the designers (red) had more self-connections to Aesthetics than the engineers did.

In the first phase, the engineering team had connections between all nodes and considered various topics from the beginning more than the design team (Table 3a). Furthermore, their discussion connected User and Functions more strongly than other nodes. In the second phase, both teams had networked with all nodes, but the connections between nodes differed. In the engineering team, the Prototyping node became the largest in the second phase, and according to the pinch point positions, the relationship between the Prototyping node and the other nodes were complementary to each other. In the graph of design team, the node User was the largest. It is shown that the designers continued the user interview until Phase 2 (Table 3b). In the third phase, both teams had similar shapes on the graphs. However, the design team was more active than the engineering team because the engineering team completed their work early (Table 3c). In the engineering team in Phase 2 (Table 3b), Vision was a response to Prototyping, but designers' Vision in Phase 3 led to Prototyping and Aesthetics (Table 3c). In other words, these graphs illustrate that the participants discussed the appearance of the product in order to complete the prototype in the final stage and that their Vision was mentioned during that discussion although the details of their discussion were different. The designers had a long user interview, so the discussion for their prototyping started later than another team. Interestingly, the design team's graph in Phase 3 was similar to the engineering team's graph in Phase 2 (Figures 3a and 3b). The designers' graph in the last phase might be the same shape as another team's one if they have more time to discuss prototyping.

The bottom graphs in Table 3 indicates the difference between engineers and designers in the framework of shared epistemic agency. These network graphs were created using the codes (Table 2) composed of two dimensions and seven categories. In the space on this graph, the knowledge-related categories ALoK are placed on the right, GCA on the upper left, and CSU on the opposite side of GCA. Process-related categories are located close to each knowledge-related category: GCA and Relational, ALoK and Projective, and CSU and Regulative.

As results of analysis on each phase, the subtracted graph in the first phase (Table 3d) shows only engineers' connections and nodes because both teams conducted user interviews to alleviate a lack of knowledge. The engineers created a shared understanding based on the actions of ALoK. By contrast, the designers concentrated on alleviating a lack of knowledge. In the second phase, they had different shapes of graphs (Table 3e). In the engineers' graphs, their largest node is GCA, which is the most advanced creative action in the framework of shared epistemic agency. On the other hand, the designers' graph has strong self-connections for ALoK. In the last phase (Table 3f), we confirmed that engineers had a strong connection between GCA and Regulative, and they were complementary to each other. By contrast, designers had a strong connection between ALoK and GCA, with GCA leading ALoK. In other words, they have collected knowledge, created shared understanding, and rapidly progressed to GCA from Phase 2 to Phase 3. Besides, graphs (c) and (d) in Figure 3 show the most prominent node of the design team in Phase 3 is GCA, like the engineering team in Phase 2.

Table 3
The subtracted graphs of ONA for each code and each phase. The blue networks denote engineers, and the red networks represent designers.

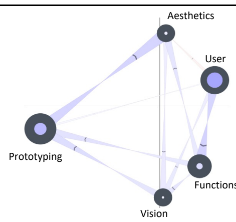
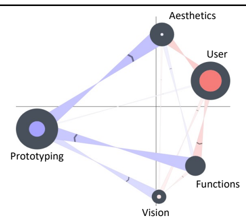
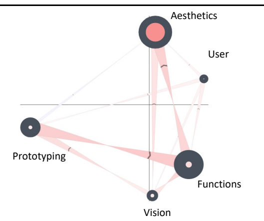
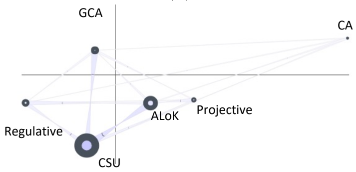
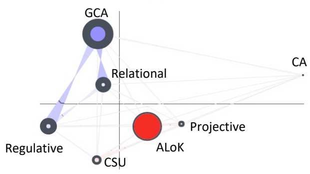
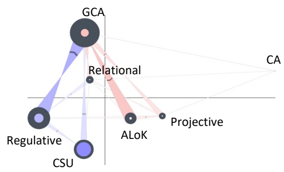
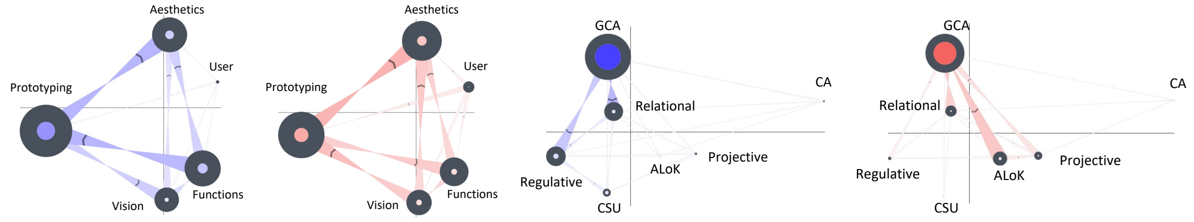
	Phase 1	Phase 2	Phase 3
Design actions	 (a)	 (b)	 (c)
Shared epistemic agency	 (d)	 (e)	 (f)

Figure 3
The results of ONA: from left (a) engineering team in phase 2 for design actions, (b) design team in phase 3 for design actions, (c) engineering team in phase 2 for shared epistemic agency, (d) design team in phase 3 for shared epistemic agency.



(a) (b) (c) (d)

Qualitative examples

To confirm the details of the participants' activities, we reviewed the discourse data and selected the pivotal scene. Tables 4 and 5 present the engineers' and designers' discussions, respectively, with GCA actions. The first author translated these data from Japanese to English and marked key terms in tSSNA in bold.

In the engineers' discourse data in Phase 2 (Table 4), they had already decided on the basic concept of their outcomes and then discussed how to improve their outcomes. First, participant EC monitored their prototype in line E237. Then, they sought to prototype better by discussing using tools, aesthetics, and functions.

Table 4
Qualitative example of engineers' discourse in Phase 2.

ID	Speaker	Utterance
E237	EC	I guess it's like this.
E238	EA	It might be easier to **paste** by **double-sided tape**, right?
E239	EC	**Paste** by **double-sided tape**…
E240	EA	Sure, it's nice because it became a little more **3-D** effect.
E241	EB	Sure.
E242	EA	It's becoming a bit like a **wallet**.
E243	EB	**Anti-skimming film** …sheet. Do you want to **paste** it on? This. **Inside**.
E244	EC	That's it, where….
E245	EB	You can put it on here.

In Phase 3 (Table 5), the designers also decided on their final concept. However, the designers asked the user to help during GCA actions (line S489 in Table 5) because they needed to know how the user held the wallet to create the prototype. The engineering team did not perform similar activities during GCA actions. This difference sometimes appears in the real design process, and this visualization by the ONA graph might support the design of co-design activities.

Table 5
Qualitative example of designers' discourse in Phase 3.

ID	Speaker	Utterance
S487	SC	Maybe, if it's just the **size** when the user holds it in her **hand**. Once we have it, we can use origami to express how large it is.
S488	SB	Oh, you're right.
S489	SC	Excuse me?
S490	User	Hi [may I help you?]
S491	SC	Um, [could you hold this one] with your **hand** like you actually hold your **wallet**? Oh, thank you very much.
S492	SB	We made a slight mistake in **time** management.
S493	SC	Yes, that's right. Could you **cut** the **tape** a little bit? Hey.

Discussion

This study aims to examine the new double-layered analysis and creative practice from the knowledge-building perspective. The first research question was (1) How can the combined tSSNA and ONA methods visualize the activities of engineers and designers as they engage in knowledge-building practices? To answer this question, we conducted tSSNA to analyze changing ideas in the teams and define phases. After that, ONA visualized epistemic agency based on the phases. As a result, tSSNA shows that both teams had changed ideas until the end of the activities. Moreover, the activities were divided into three phases based on the pattern of the key phrase density transition. Based on these phases, ONA visualized epistemic frames using two coding tables. The engineering team connected more than one node and considered various topics from the beginning in activities, although they started activities from user interviews. The ONA graph of the design team differed from the engineers', even though they too started activities from user interviews.

The second research question is (2) What are the differences among idea-changing, shared epistemic agency, and design actions between the engineering team and the design team in the short prototyping process? We confirmed that the two teams had differences in the epistemic frame. For the design actions codes, which came from design theories, ONA shows that the engineering team started creation with various viewpoints, and that their focuses moved from User to Prototype and finally to Aesthetics and Prototype. On the other hand, designers focused on the User in Phase 1. In the second phase, they discussed User, Aesthetics, and Functions. In other words, the User leads to Functions and Aesthetics design in the designers' team; furthermore, they also focused on Prototype and Aesthetics more in the late stage. For the shared epistemic agency, both teams started from ALoK. However, engineers reached GCA in Phase 2. In contrast, the design team still concentrated on ALoK in Phase 2, and they moved to GCA in Phase 3. Furthermore, we confirmed the similarity between the ONA graphs of the engineering team in Phase 2 and the design team in Phase 3 from two coding tables. This visualization suggests that if the designers had more time, their graph in the last phase might be the same as that of the engineers in Phase 3.

These results contribute to supporting learners in creative practice. First, this study suggests the advantage of combining the tSSNA and ONA methods. This combination method follows the previous double-layered analysis from the idea improvement and epistemic agency perspectives. However, this study analyzed data from the idea improvement perspective with temporality and epistemic agency with directionality. Thus, the proposed method illustrates the pattern of idea improvement and the differences in epistemic frames in the phases and teams. tSSNA showed that both teams continued to change their idea until the end of the activities. Moreover, ONA visualized that the progress of the design team, which spent more time on user interviews, appeared to track the activities of the engineering team, which completed its activities more quickly. Interestingly, the subtracted ONA graphs (Figure 3) show that the engineering team had strong connections and nodes even though the engineers had fewer lines and less activity time than the designers did. Furthermore, owing to this combination method, we confirmed pivotal scenes from the original discourse data. Hence, the proposed method will support the definition of the essential scenes from a large amount of data. Second, this study illustrated the similarities and differences between engineers and designers, such as both teams having a similar process for the design actions and idea changing, although they had a few differences in the shared epistemic agency. In other words, this study might describe a common, better creative working process.

Of course, this study has some limitations. First, the dataset was small. In the ONA results for the design codes, as the result of the Wilcoxon rank-sum exact test, there was a significant difference on the x-axis ($W = 26$, p-value = 0.02492), while there was no significant difference on the y-axis ($W = 53$, p-value = 0.6744). On the other hand, the Wilcoxon rank-sum exact test for the shared epistemic agency revealed that there was a significant difference on the x-axis ($W = 24$, p-value = 0.0169), while there was no significant difference on the y-axis ($W = 54$, p-value = 0.7223). Nonetheless, the total number of participants in both teams was six. Therefore, researching with more participants including statistical tests is necessary. Second, this study concentrated on the practitioners' data. In future work, we need to analyze learners' data. However, despite these limitations, this study reveals the advantage of the proposed method. The relationship between the two perspectives (idea changing and epistemic agency) is important for KB practices. When we advance this research, we can find the principles, such as that better practices have specific patterns in the first idea-changing phase where the TDC score rapidly increases in value.

References

Brown, T. (2008). Design thinking. *Harvard business review* 86(6), 84-92.

Barany, A., Philips, M., Kawakubo, A.J. & Oshima, J. (2021). Choosing units of analysis in temporal discourse. In: Wasson, B., Zörgő, S. (eds) Advances in Quantitative Ethnography. ICQE 2021. *Communications in Computer and Information Science*, vol 1522 (pp.). Springer, Cham. (2021)

Chen, B. & Hong, H.-Y. (2016) Schools as knowledge-building organizations: Thirty years of design research. Educational Psychologist 51(2), 266–288.
Chen, B., Scardamalia, M.,& Bereiter, C. (2015). Advancing knowledge-building discourse through judgments of promising ideas. International Journal of Computer-Supported Collaborative Learning, 10(4), 345–366.
Damşa, C. I., Kirschner, P. A., Andriessen, J. E. B., Erkens, G. & Sins, P. H. M. (2010). Shared epistemic agency – An empirical study of an emergent construct. *Journal of the Learning Sciences*, 19(2), 143–186.
Herrenkohl, L.R. & Cornelius, L. (2013). Investigating elementary students' scientific and historical argumentation. *Journal of the Learning Sciences*. 22(3), 413–461.
Kajamaa, A. & Kumpulainen, K. (2020) Students' multimodal knowledge practices in a makerspace learning environment. *International Journal of Computer-Supported Collaborative Learning*. 15 (4), 411-444.
Ohsaki, A. & Oshima, J. (2019). A Socio-Semantic Network Analysis of Discourse Using the Network Lifetime and the Moving Stanza Window Method. In Eagan B., Misfeldt M., Siebert-Evenstone A. (eds.) Advances in Quantitative Ethnography. ICQE 2019. *Communications in Computer and Information Science*, vol. 1112 (pp. 326–333). Springer, Cham.
Ohsaki, A. & Oshima, J.(2021a). Socio-semantic Network Analysis of Knowledge-Creation Discourse on a Real-Time Scale. In: Ruis A.R., Lee S.B. (eds.) Advances in Quantitative Ethnography. ICQE 2020. *Communications in Computer and Information Science*, vol 1312 (pp. 170-184). Springer, Cham.
Ohsaki, A. & Oshima, J (2021b). Knowledge Creation Analytics for Jigsaw Instruction: Temporal Socio-Semantic Network Analysis, In de Vries, E., Hod, Y., & Ahn J. (Eds.). *Proceedings of the 15th International Conference of the Learning Sciences (ICLS)* 2021(pp. 537-540). Bochum, Germany: International Society of the Learning Sciences
Ohsaki, A. & Oshima, J. (2022). Analyzing the Co-design Process by Engineers and Product Designers from Perspectives of Knowledge Building. In 2022 International Conference on Quantitative Ethnography. Copenhagen, Denmark
Oshima, J., Oshima, R. & Matsuzawa, Y. (2012). Knowledge Building Discourse Explorer: A social network analysis application for knowledge building discourse. *Educational Technology Research & Development*, 60, 903–921.
Oshima, J., Kawasaki, M., Ohsaki, A., Mehto, V., Seitamaa-Hakkarainen, P. & Hakkarainen, K. (2022). Artifact-Mediated Collective Cognitive Responsibility in Learning Through Collaborative Designing. In *CSCL2022* Proceedings (pp. 312-315), Hiroshima, Japan: International Society of the Learning Sciences
Oshima, J., Oshima, R. & Saruwatari, S. (2020). Analysis of students' ideas and conceptual artifacts in knowledge building discourse. *British Journal of Educational Technology*, 51(4), 1308–1321.
Scardamalia, M. & Bereiter, C. (2014). Knowledge building and knowledge creation: Theory, pedagogy, and technology. In: R. K. Sawyer (ed.) *The Cambridge Handbook of the Learning Sciences: Second edition* (pp. 397–417). Cambridge University Press, New York.
Scardamalia, M. & Bereiter, C. (2022). Knowledge building and knowledge creation. In: R. K. Sawyer (ed.) *The Cambridge Handbook of the Learning Sciences: Third edition* (pp. 385–405). Cambridge University Press, New York.
Shaffer, D. W. (2017). *Quantitative ethnography*. Madison, WI: Cathcart Press.
Stanford d.school. (n.d.). *Get Started with Design Thinking*. https://dschool.stanford.edu/resources/getting-started-with-design-thinking. last accessed 2022/11/13.
Tan, Y., Ruis, A.R., Marquart C., Cai, Z., Knowles, M. & Shaffer, D.W. (2022). Ordered Network Analysis. In 2022 International Conference on Quantitative Ethnography. Copenhagen, Denmark
Verganti, R. (2017). *Overcrowded*. Gildan Media

Acknowledgments