Knowledge Convergence in Collaborative Concept Mapping

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ABSTRACT

This study investigates how collaborative concept mapping tasks affect the knowledge convergence of learners. Participants are divided into two groups by different group contingency, independent and interdependent, and we analyzed their discourses. We observed that agency could strongly affect their collaboration, but verbatim recitation was not a strong indicator of knowledge convergence in this context where learners had created an individual map before collaboration, and they used it as a reference. Though we also found the process of knowledge convergence, that did not strongly indicate that learners build knowledge together in both groups. Their actual collaborative map with an informational text was not considered as the knowledge convergence outcome.

INTRODUCTION

Online discussion, either asynchronous or synchronous, has been emphasized since social interaction was one of the critical capabilities for this new normal era, according to OECD (2019). However, efforts devoted to the study of group achievement and understanding have been significantly lacking, considering the new understandings built through dynamic interaction (Fisher & Mandl, 2005). This paper extends the investigation of in-depth learning, focusing on collaborative achievement, particularly knowledge convergence, while constructing a collaborative concept map. In this study, we engaged Information Science and Technology undergraduates in collaborative concept mapping to do the summary activity of a chapter, and we analyzed learners' knowledge convergence by different group contingency from their discourse. The finding from this study can inform the development of practical instructional support within the context of learning linearly arranged information.

THEORETICAL RATIONALE

Dillenbourg (1999) defined collaborative learning as two or more people's attempts to learn something together compared to cooperation. Team members individually solve sub-tasks after splitting the work and assemble the individual's results for the outcome in cooperation, whereas individuals share and negotiate for the outcome in collaboration. Roschelle & Teasley (1995) also defined collaboration as a coordinated and synchronous group activity as a result of individual learners' consistent effort to construct and develop a shared conception of a problem. Concept mapping is a visualizing technique to organize and represent the relationships among nodes(concepts) by edges (connecting nodes) representing relationships among the concepts as a network of ideas as a part of qualitative methods (Novak & Gowin 1984; Novak & Canas, 2008). Concept mapping tasks are generally regarded as cognitively demanding tasks given complex procedures such as identifying the main concepts and finding relationships among nodes by focusing on the organizational structure of the text, simultaneously screening the learning materials (Jonassen 1997; Hay, Kinchin, & Lygo- Baker 2008). These tasks generally improve verbatim knowledge and comprehension, and inferential skills for the contents (Novak & Gowin 1984). Thus, as a learning strategy for knowledge construction, collaborative concept mapping can certainly enhance conceptual understanding (Stoyanova & Kommers 2002; Farrokhnia et al., 2019). Collaborative concept mapping tasks are essential strategies to integrate individual learning with various group learning skills, such as creating a shared meaning of the task, concepts, procedures, and strategies for knowledge construction (Van Boxtel et al., 2002). Bereiter and Scaldamalia (2003), who appear as the pioneers in the field of knowledge construction, insist the creation of knowledge only occurs in collective processes, and Jeong and Chi (2007) indicated that in-depth learning only occurs after the group members integrate reasoning into personal understanding with the shared meaning. Knowledge convergence, essential to evaluate the depth of understanding of learners, mainly focuses on mutual influence through social interaction; as such, it is a process where two or more people exchange and converge their knowledge of the problem. Through mutual understanding, the knowledge finally becomes similar, which can be called 'shared understanding' of the content (Hutchins, 1991; Rogoff, 1998; Jeong & Chi, 2007; Roschelle 1992).

Processes and outcomes are often used to explain knowledge convergence (Roschelle 1992; Jeong&Chi 2007; Fischer&Mandl 2005). The process of convergence is conceptualized in various ways. One approach is based on knowledge contribution, which emphasizes that learners should contribute the ideas to varying or similar extents by counting the number of turns in discussion (Cohen 1994). This process can include grounding (Clark & Brennan, 1991), where both parties believe both understood and contributed to the discussion. The grounding process is the bottom layer of negotiation (Dillenbourg et al., 1996) and an essential part of achieving convergence. Shared knowledge, group mind, community memory, and team mental model are often viewed in the process of knowledge convergence as contributions of mutual knowledge. However, grounding may only capture the local convergence, not lead to a global convergence in terms of both mental models (Chi et al., 2004). Roschelle (1992) indicated that conversational analysis (CA) and pragmatics are critical in knowledge convergence research as interaction provides a means to construct abstract concepts collaboratively through the gradual refinement of ambiguous meaning. In addition to knowledge convergence processes, the other aspect to explain this phenomenon is resulting outcomes or mutual understanding. The outcomes can be defined in one way as "increased similarity in the cognitive representations of the group members" (Jeong & Chi, 2007, p 288) as their knowledge will be incrementally elaborated. That is, learners mutually influence the knowledge outcomes of the group members; common knowledge or common ground are examples of outcomes of this mutual influence (Roschelle 1992; Teasley 1997; Jeong & Chi 2007; Mercier 2017). In Roschelle (1992)'s study, the outcomes of two learners were gradually similar, indicating that the similar representation as an outcome after collaboration is convergence. For example, each learner interprets a situation, adjusts their understandings, and collaborates to solve problems; this process leads to the outcome of convergence. Jeong and Chi (2007) assessed knowledge convergence quantitively by conducting pre and post-knowledge tests to see the increase in common knowledge within the group; they defined knowledge convergence as an increase in common knowledge within a group. The results of pre and post-test performance revealed that learners shared more knowledge pieces and mental models after collaboration, though the association between the amount of interaction and the increase in common knowledge was not statistically significant. The study design considered the influences of learning artifacts (e.g., concept map) besides collaborative dialogues. Another study using pre and post test measures to quantify the knowledge convergence outcome differences when students had different goal assignments (either a learning goal or a performance goal); was conducted (Mercier, 2017). Though the results did not represent the differences in having learning goals or performance outcomes, there was a difference in knowledge convergence; groups with learning goals showed more knowledge convergence than groups with performance goals, suggesting that creating achievement goals for collaboration can influence interaction behaviors.

Peterson & Roseth (2016) developed four CSCL (Computer Supported Cooperative Learning) strategies to increase students' cooperative perceptions based on the social interdependence theory: social interdependence, summarizing, scripts, and synchronicity. We particularly apply three relevant strategies to examine this small-scale research. Social interdependence (Johnson & Johnson, 1989, 2005) describes how students perceive their success as being affected by others' works, so hypothetically, the interdependent group has a more positive perception of their collaboration than the independent group. Additionally, requiring students to work on a collaborative summary should enhance collaborative perceptions because the shared goal involves active collaboration to create a group product (Ortiz, Johnson, & Johnson, 1996). Summarizing enhances achievement encouraging students to focus on the most relevant material and integrate it with existing knowledge (Hidi & Anderson,1986; Wittrock & Alesandrini, 1990), and using concept maps for summarization can even double the effects on text comprehension (Chang, Sung & Chen, 2002). In short, the greater positive goal interdependence by adding summarizing tasks with concept maps could enhance the benefit of collaboration, increasing the group productivity. Another essential part of this research is synchronicity. A synchronous video conferencing tool can enhance their collaboration by allowing them to convey social cues negotiating to construct knowledge in real-time, and researchers to analyze the processes of constructing a concept map during collaborative works. Therefore, it is critical to study knowledge convergence using a concept map with the concept of social interdependence in synchronous discussion in computer-supported learning to understand their deeper learning. This research investigates whether participants interact to share their individual knowledge and improve their conceptual understanding. Additionally, we explore their term usages to understand which terms are more frequently used together and how the terms in the interdependent group differ from the independent group.

METHOD

It occurred within the Information Sciences and Technology introductory course of 80 students at a Northeastern American university. For this particular paper, we randomly selected one independent and interdependent group to compare and analyze their discourses to understand how the collaborative concept maps are constructed differently by the group contingency to find evidence of deeper learning.

Procedure

Each group comprised three students, and they were randomly assigned to either an independent or interdependent group. The independent group students read one chapter about "system design and development" and constructed an individual concept map using the given tool, whereas the interdependent group students read one-third of the chapter and constructed an individual concept map using the same tool. After this preassigned task, both groups synchronously met and collaborated to create one map for the group. During the collaboration, students were required to create at least 20 nodes with edges but were not asked to consider the directionality of the nodes. Students were told their options not to be included in the research without any negative influences at the end. There was no time limit, and participants could look at other team members' maps. A tutorial of a tool, Cmap (Novak & Canas, 2008), was provided to instruct how to place words(nodes) with links (edges), including the directionality in advance.

RESULTS

Lexical network analysis

Based on the content-related term frequency in two transcripts, we created their lexical networks in different group contingencies and compared them to understand the difference by the group. We picked 40 relevant terms from the most frequently used terms, and networks joined in pairs by edges were generated. Modularity, based on the eigenvectors of a characteristic matrix for the network, is a highly effective measurement technique in network analysis to detect delineated clusters (Newman 2006). With this definition, we found four different term clusters with 17 nodes and 51 edges in group 1(independent) and seven clusters with 22 nodes and 114 edges in group 2(interdependent). Simply describing, there are more nodes so as more clusters and the terms in each cluster were different in groups. Though each cluster includes identical terms, slightly different terms in clusters were found by the groups—also, the average degree and average weighted degree of the interdependent group was 5.182 and 9.090, which is relatively higher than the independent group of 3 and 6.647. The graph density of both groups is low and cannot be compared because of the different numbers of nodes(Table 1).

	Independent	Interdependent
Average degree	3	5.182
Avg.Weighted Degree	6.647	9.091
Network Diameter	5	4
Graph Density	0.188	0.247
Modularity	0.303	0.204

Table 1 Lexical difference in groups

Discourse Analysis

Roschelle (1992) indicated that conversational analysis (CA) and pragmatics are critical in knowledge convergence research as interaction provides a means to construct scientific concepts collaboratively through the gradual refinement of ambiguous meaning. In his case study, the dialogues of a pair of high school students were analyzed when they collaborate to learn the concepts in physics within the concepts of conversational action, conceptual change, and shared knowledge.

Craig, Rick, and Julien (Group 1) and Malissa, Josh, and Bryce (Group 2) are undergraduates taking an introductory course in information science. The main difference in the tasks between the two groups is the content they read. The members of group 1 were assigned to read a whole chapter, while the members of group 2 were required to read one-third of the chapter. After that, group 1 individually constructed a whole map of a chapter, while group 2 members created only one-third of the map before their collaborative work. The evidence of social outcome is shared knowledge as a process for knowledge convergence. During the collaboration, ideally, learners interpret a situation, coordinate their understandings, and come up with a solution to a problem together, and this process leads to the outcome of convergence. Here we focus on knowledge convergence in socially shared meaning, and we found knowledge convergence in both groups but could not conclude their collaborative map is their knowledge convergence outcome.

Agency by grouping

"Agency refers to the capacity of an individual or group to affect change on some entity, person, experience, state… and it is also connected with the notions of power and control (Strauss and Feiz, 2014, p.293)." Two groups were required to construct a collaborative map after different task requirements: group 1 members were asked to read a whole chapter, while group 2 members were to allocate their reading by one-third of the chapter per individual for the knowledge dependency. We expected group 2 to be socially dependent on their achievement as the outcome is more likely to be affected by other members' commitment and knowledge.

Group 1, whose task was to read a whole chapter individually, caused to rise of a dominant leader. Grammatical and conceptual connotations of his utterance with controlling attitudes signified the role in the group. In their previous conversation, Craig asked what other nodes connected with the node of programming languages, and Rick suggested having programming as a node and branch off to higher-level language and lower-level language. In the excerpt below, Craig uses imperatives to provide direction, and the rest of the members agree and follow. When Rick suggests branching macro language off languages, Craig says, "that's what I will do." This sentence represents his way of agreement. Also, asking an obvious question is often used as a means of control.

Group 1- Independent

Craig – OK so then we're over here. I'll connect those in a second, just give me a sec. We'll put high level languages over here, and then while I'm connecting that you guys, uh, work on high level languages. We don't need a ton, I mean as long as we get some.

Julian – Yeah, um… low level…assembly…machine…low level…high level… [reading out of book to himself]

Craig – OK, uh…high level languages…[mumbling a little] algorithm. Oh OK, Ricky. I got you. I see what you're doing. OK, so high level languages… is that like basic and C and C++?

Rick – Yeah.
Julian – Yes.
Rick – You could also branch, uh, macro languages off of languages.
Craig - OK, that's what I'll do. Now do we have to cover the whole chapter?

Group 1- Independent
Julian - Did it – did it go across? It doesn't matter about that.
Craig – OK. Um, if you wanna move – Julius, if you wanna move Java up to the high level languages up there and I already got C++, so if you wanna move FORTRAN and- and Java up there, go ahead. OK Ricky, for macro you just had 4th generation and 5th generation?

This excerpt above is a dialogue between Julian and Craig. While Julian was constructing a part of the map individually, his link(edge) crossed the part Craig was working on. He overly reacted and indirectly instructed Julian what to do, limiting his work, and promptly changed the attention by talking to Rick obstructing utterance of Julian. These two excerpts describe his dominant behaviors showing the agency of the group. Unlike our assumption that the independent group will be more collaborative than the interdependent group because of the different content distribution, the independent group worked more cooperatively, and the agency was affected.

Group 2 represents distributed agency. Bryce interpreted the situation by asking a question about a task, and Josh provided solutions by mentioning other team members' maps shared in advance. In their decision-making process, they coordinated their understanding and came up with a solution how they wanted to work on, though the process took a long time. This is rather a collaborative process of decision-making than knowledge building of the learning content. Each member had authority or expertise in terms of the book knowledge because they all read the different sections of a textbook and constructed relevant parts of the map individually.

Group 2- Interdependent
Josh –so, if we just take systems design and development, put like a couple nodes off of it, then we can each tackle one of those nodes and just get the [Brian – Yeah.] high- the first two levels done – and then split off of a second tier.
Melissa –Right.
Bryce – Yeah.
Josh – Is that the three main categ – is that what they're – what they're - it's how people make programs, [garbled] programming languages and methodologies, and what else is there? Or is that it? Programs and perspectives? Systems analyst – analysis – and systems [garbled]?
Melissa – Yeah, it's right here…three nodes.
Josh –Then there's the science of computing. The next one…
Melissa – State of software.
Bryce - Oh, I see what you're doing. You're going through each thing.
Josh - Yup. And…that's it.
Bryce – That's it.
Josh – That's it.

Bryce – Um…OK. So, Melanie, for yours system development [Melanie – Yeah.] and lifecycle, your main points are analysis – I'm gonna write these down – analysis, design, development… Melissa- Um, OK, sorry my screen is really small so I have to go back and forth. Um, analysis, design, development, implementation… Bryce- I'll help you. Josh - You want me to – [Melanie – Yeah.] is it cool if I start going from the beginning? I'll just start, start from the 'how people make programs'? Bryce – Yeah, yeah. Um, retirement… um, implementation…oh maintenance, Melanie? OK and then… Melissa –Is that all we really need for that, or do we wanna go in-depth at all? Bryce – So with retirement we can do 'in with the old', the 'out with the new'. Melissa – Let's see… Bryce – Um, implementation…one of them is approaches to implementation. Melissa – Yeah.

In the first excerpt, about 40% of the dialogue is to express agreement. Josh suggested creating a node, "system design and development" to begin, and the collaborative map was developed with each of the personal maps. After that, Bryce checked the assigned parts, and Josh created a few key nodes from his part, asking other key nodes to connect with. This excerpt reveals that Josh is leading the direction but not in a completely authoritative manner. The second excerpt represents Bryce helping Melissa to find relevant terms to connect with retirement and implementation. Again, there was no dominant leader in group 2. When the groups are compared regarding agency, the nature of group 2, distributed content expertise, made them cooperate more with positive social dependence. In contrast, the members in group 1 had the same content knowledge, even having a personal map of the content, so ideally, they were supposed to collaborate to negotiate the connection among nodes. However, instead, one dominant figure led the group conversation with relatively low social dependence.

Verbatim knowledge as a strong indicator of shared knowledge

Verbatim knowledge often refers to the items stated directly from the original text, such as remembering facts and stating knowledge as a lower order thinking, while inferential knowledge(conceptual knowledge) refers to the items needed to connect multiple concepts such as concept formation and problem-solving as higher-order learning (Clariana & Koul 2006; Blunt & Karpicke 2014). The concept mapping tasks require both verbatim and inferential knowledge given the complex procedures of identifying the main concepts and finding relationships among nodes by focusing on the organizational structure of the text while viewing the learning materials (Novak & Gowin 1984).

The unique and confounding aspect of this dataset is that all participants have their reference maps when collaborating to construct the group map, but retrieving and reciting those individual verbatim knowledge maps cannot be the evidence of shared knowledge. Thus, the verbatim knowledge we consider here is only when they refer to the textbook. Both groups referenced their textbook but were rare because of the personal reference maps. The behavior referencing their textbook appeared when checking the connections among nodes.

Group 2- Interdependent
Bryce – What stuff? That's um…programming languages and methodologies.

Josh – What does that connect to?
Bryce – Uh…let me open my [cut out] page book.
Josh – That go…
Bryce –…connect off the center. I hate this thing. So people make programs, and then programming languages and methodologies.

Group 1- Independent
Craig- Is computer science and the science of computing – are they the same thing?
Julian – Com…
Rick – Wait, what's that?
Craig – Uh, if you – the science of computing and computer science. Are they one and the same? Are we saying the same thing there?
Julian – Uh, the, um, that starts off the, um… it starts it off. If you look on 536 –
Craig – Yeah.
Julian -that's the title: The Science of Computing.

Knowledge Convergence

Interesting part in this discourse data originates from the artifacts: individual concept mapping. As all participants construct their personal concept maps based on their assigned reading before joining a collaborative work, their knowledge should be reflected on those individual maps, which are frequently referred to during discussion in both groups. Thus, we could induce that their references in these dialogues are mostly from their personal maps and could assume that when participants refer to their own maps during the group map construction (identifying the concept), negotiation occurs, and their group maps reflect their negotiation (finding relationship among nodes), we could see them as a process of knowledge convergence.

Group 2 Interdependent
Josh - …going to connect this here. This guy really needs to go here.
Bryce – What's up?
Josh - I, I'm only, I, I'm double linking up here…going crazy.
Bryce – Wait why are you double linking?
Josh – I – cause it make sense, I guess? I don't know where I'm going…[garbled] cross the stream.
Bryce – Do that magic thing to it.

In the excerpt above, Josh tried to double link with one node, and Bryce asked why he wanted to do it, which could be evidence of negotiation if Josh explained the reasons, but Josh intuitively did it saying "cause it make sense, I guess". To them, the auto-format function, "magic thing," seems like a convenient backup skill to verify their map. This excerpt is interesting considering the aspect of knowledge convergence: Josh brought a double linking problem and cannot explain the reason. Josh and Bryce both could have referenced the textbook, but instead, Bryce suggests auto-formatting, which might solve the problem without the retrieval process, whether that is either verbatim or conceptual knowledge. Thus, we cannot find the clues of knowledge convergence.

Group 2 Interdependent
Melissa – What still needs done yet?

Josh -…program with machine language.
Bryce – Are we going to put everything underneath, or…what did you guys wanna do? I guess we'll…
Bryce – I guess we can let it auto format? Or do you wanna –
Melissa – Well the systems lifecycle should be closer to the bottom cause that was like the end of the chapter.
Bryce – What? Oh are you saying this – is this wrong? Well would – I thought this would be the center and then there would be arrow pointing to each. Is that incorrect?
Melissa – No, no, I mean that's fine. It's just like the systems development comes after the programming languages – in the chapter, at least.
Bryce – I think we're good.
Melissa – Yeah.

In the excerpt above, they are checking the parts in the map not completed yet. Josh found a part (program with machine language) that needs attention, and Bryce suggested intuitive solutions, either putting everything underneath based on his knowledge or autoformatting. Melissa doubted his solution as she thought the node should go down to the bottom of the map because she assumed the terms in the textbook are chronologically delivered, which is incorrect. Bryce expressed his thought with reasoning, and Melissa did not rebut the point Bryce made but confirmed her understanding was slightly inaccurate in that system development should come after the programming languages. This dialog looks like a weak version of the negotiation process.

Group 2 Interdependent
Josh – It's gotta go there like that. That guy's gotta go there. [last part garbled] …get this over here…and then put this one…
Bryce – Do you just wanna do the [middle part cut out] the whole thing?
Josh – Uh it gets, I mean if we do it, we can try- we can try it out – Whoa! Whoa, what's go- what just happened? Hold on.
Melissa – Oh no.
Josh – That made no sense. Yeah that got bad real quick. Um the auto-format thing can sometimes mess up, so if we do it we gotta just one person do it so they can -can- they can undo it if it doesn't look right. But I think we're looking kinda good. It's pretty good. Well except for that one down there.

Before this excerpt above, the auto-formatting function had helped them organize the map, which led them not to deal with complex conceptual understanding connecting distributed concepts. Josh structured the map, and Bryce wanted to use the autoformat function again to make sure Josh was right. They realized this function does not always provide the solution indicating this team could at least notice when the map goes wrong. Each member's knowledge was not entirely engaged in this collaborative concept mapping process: they tried to solve problems working on the group map but did not show deeply engaging conversation using their individual knowledge.

Group 1- Independent
Craig – OK Rick, would you say macro languages off of languages as well?

Rick – Yeah...so then there's um, you can have 4th generation languages and 5th generation languages.
Craig –for macro you just had 4th generation and 5th generation?
Rick – No, uh, make, make those just go off of languages too.
Craig - Oh just – oh just keep macro languages by itself then?
Rick – Yeah.
Craig – OK.
Rick – And under 4th generation you could have query language. And that's all I had for – that's all I had before for that.

Craig - OK and you want me to do languages by itself?
Rick – Yeah like have, uh, programming like branch off of languages.
Craig – Like that?
Rick – Yeah and then connect them. Yeah.
Craig – OK, OK. So we do programming, we do languages. I remember there's – there's like what? There's hi – there's, uh, low level and high level languages, right?
Rick – Yeah.

In the above two excerpts, members structurize the map to organize terms. Their dialogues above are questioning from Craig and answering and confirming from Rick. Craig primarily relies on the opinions of Rick, and Rick refers to his personal map. There is no further negotiation process as proof of converging knowledge, so their symmetry of knowledge in the content seems slant toward Rick even though all are supposed to read a whole chapter.

Group 1- Independent
Craig- computer science as one and then, um, off of computer science I actually had a ton, so I'll work on that and then the other- the other big one that I had was system development lifecycle. I'm not sure if you guys had that or not.
Rick – Wait, what was the first one you had?
Craig – Computer science.
Rick – OK.
Craig – And then off of that was like I had – uh, actually from that one right there, that node – I had computer theory, algorithms, data structures, uh, programming concepts and languages, management information systems, software engineering, and computer architecture. There's a ton.
Rick – Yeah… Maybe we should put a node for like, um, chapter four – the name of chapter 14 somewhere? Then we could connect like the two main ones to that.
Julian – That's – that's what we started with.

In comparison to the interdependent group (group 2), the collaboration of group 1 was superficial even though we assumed they were supposed to have an in-depth discussion as all members read the entire chapter. For example, some cognitive outcomes, a conceptual change based on the verbatim knowledge from the textbook, were expected by in-depth discussion to construct the map but not observed. There were some moments of shared knowledge, such as checking where each one is at in order to discuss from there, but that did not clearly represent knowledge convergence. The shared knowledge here is considered as a contribution of mutual knowledge in the process of grounding.

When it comes to the Cmap tool, group 1 did not desire to explore other functions besides connecting nodes to construct a map, whereas group 2 used the tool effectively to connect a chunk of nodes to another chunk though it became a time-saving tool not to do complex thinking. Whenever they were in problems connecting vertices, they agreed to use that auto format though they eventually learned this function did not always work. Finding relationships among nodes by focusing on the organizational structure of the chapter involves inferential and higher-order thinking.

Agency in knowledge convergence

We examined how the distributed agency affects the knowledge convergence compared to the concentrated agency. A context engenders different levels of collaboration: the collaborative work is more likely to be effective with people having a similar status and action (Dillenbourg, 1999). The agency particularly influenced the symmetry of action in this case. Craig's controlling and initiative manners led to unbalanced communication in collaboration. For example, turn-taking between Craig and Rick and Craig and Julian was more than 95%. From the beginning, Craig referred to Rick's map complementing and asked his opinions, and those Q&A style interactions were maintained until the end. His questions at the beginning were to distribute their mapping tasks and later to ensure specific nodes with links were right. Craig mainly initiated conversation without intent to learn; he has never tried to validate reasons or rationalize the concept, so there seem rare opportunities to converge their knowledge while constructing the map. This discussion, driven by one leader with this type of conversation, Q&A, did not lead members to converge their knowledge to identify the main concepts and find relationships among vertices.

However, the members of the interdependent group with the relatively distributed agency were more actively participated in elaborating the map by finding relationships referencing their textbooks. This distributed agency positively affects knowledge convergence. There were conflict-oriented consensus and integrate-oriented consensus (Weinberger and Fischer, 2006). For example, when Bryce asked the overall structure of the map to connect different chunks of nodes, two members replied, and that process went on for a couple of minutes (shared knowledge) while looking at the common map to decide the path of some nodes. Even though certain words were not explicitly spoken, interlocutors understood, and they maintained their interaction. Regarding the tool, they had a good collaborative process while exploring the tool; Josh tried to use a specific tool function, auto-format, to organize it. Melissa knew how to do it, and Bryce was interested in applying it.

Group 1- Independent
Craig- Um, tell me what goes, uh, Julius – what I would go to from low level languages?
Rick – Well low level's, um, machine and assembly languages.
Julian – Yeah I see machine, yeah.
Craig – OK hold on.
Julian – It says, it says, uh, machine, assembly, assembler, and low level.
Craig – OK.
Julian – And high level is completely separate.
Craig – OK. Machine is one –
Julian – So you could –
Craig – What – what are the other ones? Assembly?

Julian – Yes. Rick – Yeah. Craig – And what was the third one? Julian – Um... low level. Craig – Oh I thought machine and assembly were low level? Oh I think that's it. Rick – Those are the only two that – those are the only two I had in mine.

CONCLUSION

Online discussion, either asynchronous or synchronous, has been emphasized as an effective instructional strategy. In this research, we tried to investigate knowledge convergence while constructing a collaborative concept map, and little knowledge convergence as a clue of deeper learning in these two cases was found. The required individual task, drawing a concept map in advance, influenced collaborative work as most students rely significantly on their individual maps regardless of their groups, which is likely to reduce the situation for socially sharing meaning. Having an additional artifact, a concept map, obstructs students' discussion, so even if there was knowledge convergence, that was not observed. Also, creating a concept map with the unfamiliar tool was already an arduous task whose cognitive loads are probably negatively affected. That is, there were too many confounding factors to affect their knowledge convergence in their collaborative work. Instead of negotiating to connect nodes, students just used a certain function of the tool to avoid complex thinking, intuitively connected nodes, and passively accepted others' thoughts. Furthermore, knowledge convergence was not frequently observed in collaborative work when the content builds foundational knowledge. The group difference reveals a slight difference in their collaborating process in extent, but we could not find an absolute difference in knowledge convergence by analyzing the discourse in terms of grouping.

Finally, a verbatim recitation of a concept or inference rule was searched as this will be the strong evidence of shared knowledge. Their verbatim recitations were either from the textbook or their individual maps, but these recitations were not evidence of shared knowledge. Those citations were only the references. We assume it is because the content itself is not meaningfully interrelated but linearly arranged to the novice, unlike the concepts of Physics (Roschelle 1992). There still can be a negotiable place for knowledge convergence, but participants should understand the contents more thoroughly to interactively communicate for negotiating to link the nodes to reach that point. Future research will be needed to focus more on the attributes of knowledge convergence and design the intervention accordingly.

REFERENCES

Blunt, J. R., & Karpicke, J. D. (2014). Learning with retrieval-based concept mapping. *Journal of Educational Psychology*, *106*(3), 849.

Chi, M. T., Siler, S. A., & Jeong, H. (2004). Can tutors monitor students' understanding accurately? *Cognition and instruction*, *22*(3), 363-387.

Clariana, R. B., & Koul, R. (2006). The effects of different forms of feedback on fuzzy and verbatim memory of science principles. *British Journal of Educational Psychology*, *76*(2), 259-270.

Clark, H. H., & Brennan, S. E. (1991). *Grounding in communication.* In L. B. Resnick, J. M. Levine, & S. D. Teasley (Eds.), *Perspectives on socially shared cognition* (p. 127–149). American Psychological Association. https://doi.org/10.1037/10096-006

Dillenbourg P. (1999) What do yuo mean by collaborative leraning?. In P. Dillenbourg (Ed) Collaborative-learning: Cognitive and Computational Approaches. (pp.1-19). Oxford: Elsevier

Pierre Dillenbourg, David Traum. Sharing solutions: persistence and grounding in multi- modal collaborative problem solving. The Journal of the Learning Sciences, 2006, 15 (1), pp.121-151. ff10.1207/s15327809jls1501_9ff. ffhal-00190698f

Farrokhnia, M., Pijeira-Díaz, H. J., Noroozi, O., & Hatami, J. (2019). Computer-supported collaborative concept mapping: The effects of different instructional designs on conceptual understanding and knowledge co-construction. Computers & Education, 142, 103640.

Hay, D., Kinchin, I., & Lygo-Baker, S. (2008). Making learning visible: The role of concept mapping in higher education. Studies in Higher Education, 33, 295-311. doi: 10.1080/03075070802049251

Hutchins, E. (1991). The social organization of distributed cognition.

Jeong, H., & Chi, M. T. (2007). Knowledge convergence and collaborative learning. Instructional Science, 35(4), 287-315.

Jonassen, D.H. Instructional design models for well-structured and III-structured problem-solving learning outcomes. ETR&D 45, 65–94 (1997). https://doi.org/10.1007/BF02299613

Novak, J. D., & Gowin, D. B. (1984). Learning how to learn. New York, NY: Cambridge University Press. doi:10.1017/CBO9781139173469

Novak, J. D., & Cañas, A. J. (2008). The theory underlying concept maps and how to construct and use them.

OECD (2019), Working and Learning Together: Rethinking Human Resource Policies for Schools, OECD Reviews of School Resources, OECD Publishing, Paris, https://doi.org/10.1787/b7aaf050-en.

Perret-Clermont, A. N., Perret, J. F., Bell, N., Resnick, L. B., Levine, J. M., & Teasley, S. D. (1991). Perspectives on socially shared cognition.

Rogoff, B. (1998). *Cognition as a collaborative process.* In W. Damon (Ed.), *Handbook of child psychology: Vol. 2. Cognition, perception, and language* (p. 679–744). John Wiley & Sons Inc.

Roschelle, J. (1992). Learning by collaborating: Convergent conceptual change. *The journal of the learning sciences*, *2*(3), 235-276.

Roschelle, J. (1996). Learning by collaborating: Convergent conceptual change. In T. Koschmann (Ed.), CSCL: Theory and practice of an emerging paradigm (pp. 209e248). Mahwah, NJ: Erlbaum.

Roschelle, J., & Teasley, S. D. (1995). The construction of shared knowledge in collaborative problem solving. In C. O'Malley (Ed.), Computer supported collaborative learning (pp. 69e97). Berlin: Springer.Rogoff, B. (1998). Cognition as a collaborative process.

Roschelle, J. (1997). *Learning in interactive environments: Prior knowledge and new experience* (pp. 37-54). San Francisco, CA: Exploratorium Institute for Inquiry.

Strauss, S., & Feiz, P. (2013). *Discourse analysis: Putting our worlds into words*. Routledge.

Stahl, G., Koschmann, T. D., & Suthers, D. D. (2006). CSCL: An historical perspective.

Stoyanova, N., & Kommers, P. (2002). Concept mapping as a medium of shared cognition in computer-supported collaborative problem solving. Journal of Interactive Learning Research, 13, 111-133

Teasley, S. D. (1997). Talking about reasoning: How important is the peer in peer collaboration?. In *Discourse, tools and reasoning* (pp. 361-384). Springer, Berlin, Heidelberg.

Teasley, S., Fischer, F., Dillenbourg, P., Kapur, M., Chi, M., Weinberger, A., & Stegmann, K. (2008). Cognitive convergence in collaborative learning.

Van Boxtel, C., van der Linden, J., Roelofs, E., & Erkens, G. (2002). Collaborative concept mapping: Provoking and supporting meaningful discourse. Theory into practice, 41(1), 40-46.

Weinberger, A., Stegmann, K., & Fischer, F. (2007). Knowledge convergence in collaborative learning: Concepts and assessment. *Learning and instruction*, *17*(4), 416-426.