Using Rotating Leadership to Visualize Students' Epistemic Agency and Collective Responsibility for Knowledge Advancement

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Abstract: As in knowledge-creating organizations and Collaborative Innovation Networks (COINs), students in Knowledge Building classrooms work creatively with ideas in a self-organized fashion, with all members engaged in advancing emergent community goals. In this study, we examined the online knowledge work of 9-year-olds studying light and shadows. Data triangulation at multiple levels of analysis (e.g., community, students, teacher) was used to validate the COIN concept of rotating leadership to assess students' collective responsibility for knowledge advancement. Overall, we found many students leading the group at different points in time, facilitating the spread of diverse ideas that enhanced the breadth of community knowledge and the depth of individual learning. Teacher perceptions of classroom dynamics uncovered additional details of student leaders, such as their level of engagement and their learning outcomes. The practical implications of rotating leadership for assessing Knowledge Building community dynamics – such as epistemic agency and collective responsibility – are discussed.

Introduction

Over the last decade, educational reform initiatives, such as Partnership for 21st Century Skills (2005), Design Thinking for Educators (2013), and Building Cultural Capacity for Innovation (2016), have been adopted in schools around the world to address various needs of innovation-driven societies (OECD, 2010). Of particular interest are schools in Ontario and Singapore, which have been successful at sustaining innovative practices in classrooms while continuously improving student achievement (Mourshed, Chinezi, & Barber, 2010). This study builds on existing research on educational innovations in Ontario schools (e.g., Zhang, et. al., 2011) and Singapore schools (e.g., Tan, So, & Yeo, 2014), with a focus on knowledge creation in primary education.

Knowledge Building (Scardamalia & Bereiter, 2014) represents a longstanding international initiative aimed at transforming schools into knowledge-creating organizations. Simply defined, Knowledge Building "is giving students *collective responsibility* for idea improvement" (Bereiter & Scardamalia, 2014). Knowledge Building takes an idea-centered, principle-based approach to classroom teaching (Hong & Sullivan, 2009) and is further distinguished from more generic forms of collaborative learning (O'Donnell & Hmelo-Silver, 2013) by transfer of responsibility for knowledge advancement to students so that responsibilities traditionally reserved for teachers (e.g., setting knowledge goals, monitoring knowledge growth, and assessing individual- and group-learning) are shared and negotiated between all members. Teachers support students' *epistemic agency* by encouraging students to take ownership of their learning at the highest levels (Scardamalia, 2002). Students generate *authentic problems* of understanding and collaborate in flexible groups that emerge and disband as needed in order to sustain collective efforts at *improving ideas* and creating coherence among *diverse ideas* in the community knowledge (*rise above*) (Zhang, Scardamalia, Reeve, & Messina, 2009).

The flexible, self-organizing dynamics in Knowledge Building classrooms mirror those of knowledge-creating organizations (Nonaka & Takeuchi, 1995) and Collaborative Innovation Networks (Gloor, 2006), where innovative cultures are fostered bottom-up through the valuing of members' intentionality, autonomy (and *epistemic agency*) during creative group processes. Despite their varied contexts (i.e., schools, organizations, virtual networks), a comparison of their underlying similarities allows further elaboration of our understanding of knowledge-creating dynamics (Ma, Matsuzawa, & Scardamalia, 2016). For example, Collaborative Innovation Networks (COINs; Gloor, 2006), as found in open-source communities, health care institutions, and knowledge-creating organizations, work collaboratively in powerful online environments to drive innovations around the world. Members share collective responsibility for their knowledge work and monitor group progress with a set of online metrics that measure their degree of connectivity, interactivity, and sharing (Gloor, 2006). Gloor and colleagues (2003; 2007) found that whereas highly efficient teams operate in a centralized fashion with a stable set of leaders, highly innovative teams, such as COINs, operate in a decentralized fashion with various emergent leaders rotating leadership over the course of a project. Moreover, rotating leadership is considered a key indicator of group creativity of COINs (Gloor, 2006). Recent work in education (Ma, Matsuzawa, Chen, & Scardamalia, 2016; Ma, 2016) suggests that Knowledge Building classrooms operate in a COINs fashion, with rotating leadership as an emergent phenomenon of collective responsibility. Findings from four cases in Ontario consistently revealed that more than half the students emerged as leaders over the course of their Knowledge Building online. When leading, students were connecting "big" ideas in the community knowledge through various types of contributions, such as questioning, theorizing, introducing ideas, and synthesizing ideas – discursive moves consistent with the ways of contributing to Knowledge Building dialogue framework developed by Chuy and colleagues (2011). However, one limitation is that these studies did not include the teacher's intended nor perceived pedagogical outcomes. The current study has two aims: to examine Knowledge Building community dynamics in a cross-cultural context and to integrate various data sources to inform our interpretation of rotating leadership in Knowledge Building. Thus, the study focuses on a Knowledge Building classroom in a Singaporean context and examines *collective responsibility* for *idea improvement* at three levels of analysis: the community, the students, and the teacher. The research questions are as follows:

1. At the community-level, is there rotating leadership? How does the emergence of student leaders correspond to pivotal points of knowledge advancement in the community knowledge?
2. At the student-level, which "big" ideas are student leaders discussing? How do those ideas correspond to the "big" ideas reported in their portfolios at the end of the intervention?
3. At the teacher-level, how does rotating leadership correspond to their perceptions of student engagement and community knowledge advancement during Knowledge Building?

Methods

In acknowledging the Knowledge Building classroom as a complex, dynamic system, we framed the research questions at three levels of analysis and adopted a multi-level mixed methods design (Creswell & Plano Clark, 2011) in order to triangulate across the levels and gain a more holistic perspective of community dynamics.

Classroom context

As mentioned above, Singapore represents a Knowledge Building hub of innovation. The current study took place in an all-girls primary school located in a middle income area. The school has been participating in the Knowledge Building initiative in Singapore over the last two years. Teachers at the school work in a professional learning team with the shared goal of fostering a culture of sustained work with ideas in their classrooms while addressing the rigid demands of the nationally mandated curriculum. In their professional learning team, teachers build knowledge about the science curriculum; create, share, and refine Knowledge Building practices; as well, they integrate Knowledge Forum technology in their classrooms in order to support students' development of scientific literacy, collaboration skills, and self-directed learning. The Primary 3 science teacher has been engaged in design-based research (Barab, 2014) for 3 design cycles over 18 months in order to systematically improve their Knowledge Building practices by focusing on a set of targeted Knowledge Building principles each cycle. During the first cycle, the teacher focused on creating an idea-centered classroom culture (e.g., *authentic problems, improvable ideas, idea diversity*). During the second cycle, the teacher focused on constructing explanations of scientific phenomena (e.g., *improvable ideas, idea diversity, Knowledge Building discourse*). During the third cycle, the teacher focused on fostering collective responsibility for knowledge advancement (e.g., *collective responsibility, community knowledge, constructive use of authoritative sources*). This study represents the fourth design cycle, where the teacher supported students in sustaining their Knowledge Building discourse as they worked toward increasing the explanatory power and coherence of their ideas (e.g., *epistemic agency, improvable ideas*). During this pedagogical intervention, students discussed features of powerful scientific explanations (e.g., claim, evidence, reasoning, logic) and worked collaboratively to improve the conceptual coherence of their community knowledge. Students generated ideas, co-constructed explanations, critiqued each other's theories, considered alternative perspectives, and actively revised and synthesize ideas in the community knowledge. As much as possible, the teacher provided minimal direction in order to allow their students to take ownership of their Knowledge Building.

The Primary 3 science class consisted of 35 students (9 year-olds) coming from a variety of ethnic and cultural backgrounds (e.g., Asia, Europe, Africa). 4 students were excluded from this study due to moving overseas and other logistical reasons; therefore 31 students were included for analysis. Because the Singapore Primary Science Curriculum begins in Primary 3, students had not been exposed to a formal science curriculum prior to the study, but they were familiar with Knowledge Building and Knowledge Forum, which had become integrated into daily science classroom practices since the first design cycle. Knowledge Forum (Scardamalia, 2004) is an online networked environment designed for collaborative knowledge creation, with scaffolds in place to support continual idea improvement. Ideas are represented as multimedia objects in conceptual spaces called views. Ideas can be searched, annotated, referenced; improved with "build-on" notes; and synthesized into more comprehensive theories with "rise-above" notes. Knowledge Forum served as the central community space for students to visualize, actively monitor, and advance the ideas in their community knowledge.

Over the span of one month, the students engaged in Knowledge Building about light and shadows, developing theories about how light travels, how shadows are formed, how the eye sees, and how light energy works. Students wrote 170 notes across 3 views in Knowledge Forum: Light and Shadows, How can we see?, and Manipulating Light. Using embedded, formative assessment tools, the teacher facilitated reflective discussions with the class as a whole in order to assess and sustain group progress. For example, the scaffold growth tool was used to visualize the distribution of students' online contributions and determine next steps to advance the community knowledge. The promising ideas tool was used to identify ideas that had the greatest potential to enhance existing scientific explanations. Promising ideas and theories were then tested and refined through various inquiry activities supported by the teacher. Students compared shadows at different times of day in order to understand how the size of shadows vary as a function of the angle of the light source in relation to the object. Their understanding was further elaborated after they watched a video of a shadow show, which prompted their thinking about the relationship between the distance of the screen, the light source, and the object. Students then designed and conducted experiments to understand how light reflects off different surfaces and how light enables the eye to see. Working in small groups, they investigated the relation between light and shadows by manipulating a set of variables of their choice, such as light source (distance, intensity, angles), objects (shapes, texture, colour, size), and screen (distance). At the end of their Knowledge Building, students created portfolios to summarize the "big" ideas they had learned.

Data sources and analyses

Multiple data sources and analytic methods were used in order to address the different questions at each level of analysis. At the community-level, the student discourse on Knowledge Forum was used to conduct temporal network analysis and explore rotating leadership, then discourse analysis was performed on the first 100 notes to identify pivotal points of knowledge advancement. All 170 notes were spellchecked and exported into KBDeX (Knowledge Building Discourse Explorer; Oshima, Oshima, & Matsuzawa, 2012), which performs social-semantic network analysis based on a list of content-related words and produces network visualizations of the student discourse. The learners network (see Figure 2a) and the words network (see Figure 2b) are created via the co-occurrence of key words in each network, with the strength of connections represented by the thickness of edges between nodes. KBDeX also creates temporal visualizations of network metrics, such as betweenness centrality, which indicates a member's influence relative to other members in the group on a scale from 0 (low) to 1 (high) (Gloor et. al., 2003). This KBDeX feature was used to conduct temporal network analysis.

The temporal visualization of betweenness centrality (see Figure 1) was then used to identify the first four leaders that emerged during Knowledge Building. At the student-level, analysis involved using KBDeX to explore the position of each student leader within the learners network and the keywords used in the word network, then content analysis was conducted on the notes and the portfolio of each student leader. The student notes helped shed light on which "big" ideas student leaders discussed and how those students contributed to the community knowledge. In turn, the student portfolios helped clarify the relation between student leadership and learning outcomes, such as idea improvement, by making the individual learning process more transparent. The teacher-level analysis involved content analysis of the teacher journal then a follow-up interview. The journal entries helped provide insight on the Knowledge Building process and whether or not the teacher perceived students were assuming *collective responsibility* for *idea improvement*. The follow-up interview involved the teacher discussing community dynamics and student outcomes relative to the rotating leadership visualizations created in KBDeX (Figures 1 to 5). It concluded with the teacher reflecting on the potential for these visualizations to support them and their students in Knowledge Building.

Findings

In this section, we describe the findings at the community-level (e.g., temporal network analysis, discourse analysis), student-level (e.g., social network analysis, content analysis), and teacher level (e.g., content analysis, interview).

Community-level analyses

Temporal network analysis suggests that many students were simultaneously influential at different times. Figure 1 shows the betweenness centrality of all students over the course of their Knowledge Building, where the Y axis represents the betweenness centrality value, and the X axis represents the turn in discussion. A different coloured line is used to represent each student, and the oscillation of coloured lines illustrates the phenomenon of rotating leadership. Of the 31 students, 19 students took a leading position. The legend in Figure 1 indicates that Students 1, 11, 22, and 19 emerged as the most influential leaders during the first 100 turns in discussion. These student leaders and their contributions are examined in further detail in the subsection below.

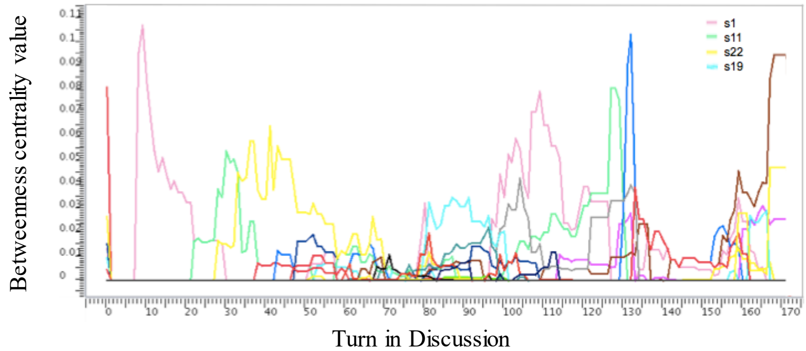

Figure 1. Temporal visualization of betweenness centrality of all students from turn 1 to turn 170.

Discourse analysis on the first 100 notes across the three views revealed that student ideas and theories surrounding various problems of understanding became increasingly more scientific and sophisticated. In the discussion about light and shadows, students generated theories about the size of shadows based on the distance between the object and the light source. Their theories were then improved by examining how properties of the object, such as opaqueness and texture, affect the way light travels and in turn, how shadows are formed. The discussion about how the eye sees grew out of a student's observation that we cannot see without light. Students then consulted authoritative sources to understand how lenses refract light to help the eye see objects and how raindrops refract light to help the eye see colours in the rainbow. In the discussion about the properties of light, students originally hypothesized that light travels in a straight line. After reading about electromagnetic radiation and photons, students began considering an alternative theory that light travels in a wave. Later on, the discussion was reframed from the perspective of natural and artificial sources of light. Students then began theorizing that light is energy and further improved their theory by comparing various sources of energy, such as chemical and electrical energy, at the end of the first 100 notes. The ideas that emerged in the pivotal points of knowledge advancement overlap with the key concepts taught in the "Gadgets Work Wonders" module in the Singapore Upper Secondary Science Curriculum (Ministry of Education Singapore, 2013, p. 32-37), where secondary students (i.e., 15 to 17 year-olds) explore the relations between energy, waves, forces, and electricity.

Individual-level analyses

Student 1

Student 1 was leading between turns turn 9 to turn 30 and peaked at turn 10 (betweenness centrality = 0.107).

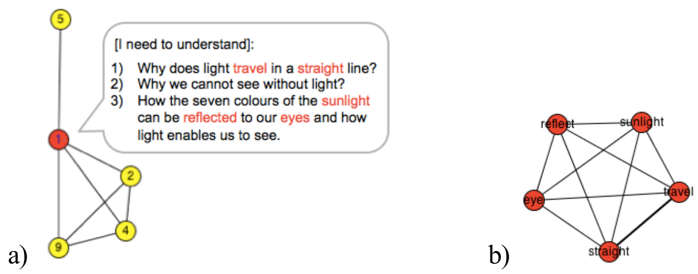

Figure 2. a) Student network and b) word network visualizations at turn 10 when Student 1 was leading.

Figure 2a shows the note Student 1 contributed that resulted in their occupation of an influential position in the student network. Student 1 contributed the first note in Knowledge Forum by defining their problems of understanding and asking deep questions that sparked the interest of their peers so much that this note was highlighted as a promising idea in the Lights and Shadows view. Figure 2b shows that Student 1 introduced important ideas in the community discourse, such as "sunlight", "reflection", and "eye", which would later appear in discussions about sources of light and energy, experiments manipulating light, and how the eye sees. It is interesting to note that while Student 1 had the greatest influence, their peers also influenced their learning. For example, Student 11 introduced the idea of "transparency", which helped Student 1 develop a more nuanced understanding of how light travels and creates shadows. Below is an excerpt from Student 1's portfolio:

> Light moves in a straight line, creating shadows when the path of light is blocked. More solid things will have a darker shadow. Things that are more clear have a lighter shadow, and transparent things will have none or very little shadow. Light can pass through transparent things the most easily. Our eyes react to light when we see something we see the light it reflects, or the light it emits.

Student 11

Student 11 was leading between turn 24 to turn 39 and peaked at turn 32 (betweenness centrality = 0.054).

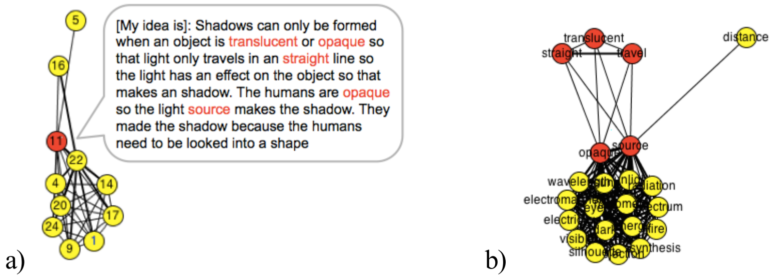

Figure 3. a) Student network and b) word network visualizations at turn 32 when Student 11 was leading.

Figure 3a shows the note Student 11 contributed that resulted in their occupation of an influential position in the student network. The problem of understanding at this time was about light and shadows, and students were wondering about how different sizes of shadows are made. Students investigated the size of shadows from the perspective of the light source, theorizing that the distance of an object from the source of light will affect the size of the shadow. Student 11 developed an alternative theory about shadows, by reframing the discussion in relation to the properties of the object, such as "translucent" and "opaque" objects. Figure 3b shows how Student 11's ideas are connected to the ideas in the larger discussion of light and shadows. While Student 11 introduced new ideas to the community knowledge, they also learned about ideas introduced by their peers. For example, Student 19 and Student 22 discussed extensively the idea of light as "energy", which helped Student 11 develop a nuanced understanding of the properties of light. Below is an excerpt from Student 11's portfolio:

> [Putting our knowledge together]: Light is a source of energy and is not matter as it does not occupy space or have mass. Light helps us see thing as it bounces off of other objects and shines into our eyes and when it is reflected at an opaque object, it will make a shadow… Light travels in a straight line but it can be directed to different directions in a zig zag manner with mirrors.

Student 22

Student 22 was leading between turn 30 to turn 71 and peaked at turn 43 (betweenness centrality = 0.065).

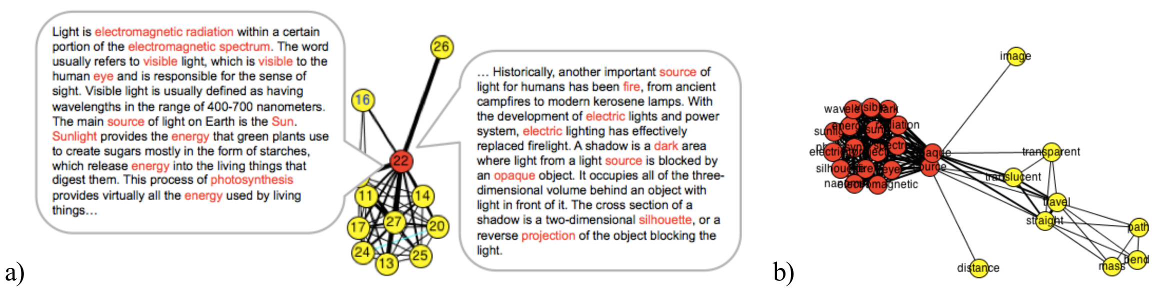

Figure 4. a) Student network and b) word network visualizations at turn 43 when Student 22 was leading.

Figure 4a shows the two notes Student 22 contributed that resulted in their occupation of an influential position in the student network. In the first note, they introduced new ideas about properties of light, explaining that light is "electromagnetic radiation" and how the eye is able to see portions of the "electromagnetic spectrum". Student 22 also highlighted the importance of light in nature by connecting the class discussion of light (in physics) to "photosynthesis" (in biology). In the second note, they synthesized their ideas about sources and light and their peer's ideas about "silhouettes" and "opaque" objects. Figure 4b shows how the many ideas contained in Student 22's notes are connected to the class discussion about how light travels and how the eye sees. Although Student 22 had the longest influence, it is unclear who influenced their learning because Student 22's portfolio was not available for analysis.

Student 19

Student 19 was leading between turn 82 to turn 102 and peaked at turn 89 (betweenness centrality = 0.035).

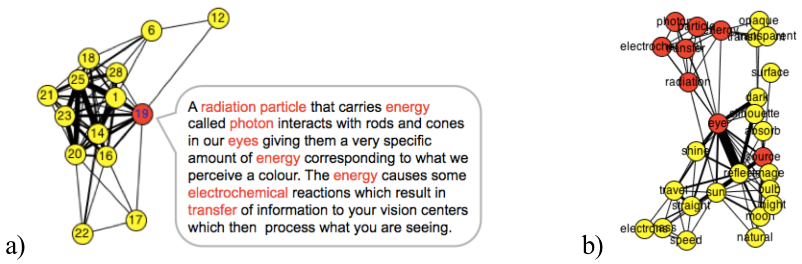

Figure 5. a) Student network and b) word network visualization at turn 89 when Student 19 was leading.

Figure 5a shows the note Student 19 contributed that resulted in their occupation of an influential position in the student network. The problem of understanding at this time was about light and shadows. Student 19 introduced the idea of light as "energy" and vision as an "electrochemical" reaction. Figure 5b shows how Student 19's ideas are connected to the class discussion about how the eye sees and sources of light. It is interesting to note that Student 11 grappled with the most sophisticated idea about light as "energy" and "photons", and their understanding of the properties of light was slightly more scientific and complex than that of their peers. Below is an excerpt from Student 19's portfolio:

> [Putting our knowledge together]: Light travels in a straight line. There is not only a straight line, but there are many straight lines. Light bounces off the object into our eyes. Shadows can only be formed with translucent and opaque objects. Transparent object allows all light to pass through. Shadows are not only black or grey but they can be multi-coloured.

Teacher-level analyses

In their journal, the teacher reflected on the classroom practices they used to encourage students to take initiative to create coherence of ideas. Some effective practices included: explicitly teaching how to construct scientific explanations using the "claim, evidence, reasoning" and "premise, reasoning, outcome" models; applying heuristics to write clearly on KF (such as crafting explanations for younger audiences so that students would unpack sophisticated ideas in their notes); and developing criteria with students for judging promising ideas. The teacher supported students in evaluating the state of their community knowledge by querying whether their problems of understanding had been addressed, whether new questions had emerged, and asking students to compare their ideas with other "big" ideas in the curriculum. Moreover, the teacher was intentional about supporting students' ideas without overshadowing them. For example, instead of giving students a set of questions to answer for their light experiments, the teacher encouraged students to pursue their own questions in order to gain a deeper understanding of the causal mechanisms of the phenomena under study. Over the course of the intervention, the teacher observed that students became more deliberate in their KF posts, posing questions constructively, and taking on higher levels of *epistemic agency* and *collective responsibility*.

During the follow-up interview, the teacher shared their classroom experiences and reflected on the rotating leadership visualization. The teacher was surprised that the most active students during class were not picked up in KBDeX. However, upon further consideration, they suggested that the rotating leadership may tap into the KB principle of *epistemic agency*, picking up "value-adding" students without their knowledge. The teacher also noted that some students picked up as leaders were quieter or academically weaker students. Those students asked deep questions on KF, worked diligently throughout, and went beyond their expectations. What's more, the weaker students did well on their summative assessment, suggesting that their active participation in KF supported individual learning. Below is an excerpt of teacher comments during the interview:

> The rotating leadership visualizations provided another layer of analysis for myself as the identities of the 'leaders' of discussion were different to that of what I had in mind. As the visualizations were able to make connections on how the lesson progressed and how members of the class contributed to the progress, it would have been a helpful tool when implemented perhaps half-way through the unit. I could have used the analysis to direct the discussions towards more instrumental contributors [who enhanced the] connectedness of ideas… Moving forward, I would want to allow students to identify their own leaders for discussion.

Conclusions and future directions

This study represents the fifth case of rotating leadership in Knowledge Building. Our findings demonstrate that collective responsibility for knowledge advancement, as depicted by oscillating patterns of betweenness centrality in the student network, is consistently found in Knowledge Building classrooms, even across cultural contexts with diverse populations. In this class, 19 out of 31 students were leaders. When leading, students asked deep questions, generated theories, shared novel ideas, and/or synthesized existing ideas in order to increase the conceptual coherence in the community knowledge. Furthermore, these ideas were uptaken by other students in their portfolios, suggesting that rotating leadership also facilitates the spread of ideas between students. As students pursue ideas in complex, unpredictable directions, a major challenge is charting their trajectory of idea improvement in order to assess individual progress and group progress. Here, we highlight a point of convergence between the current case and the Ontario case of 9 year-old students studying light (Ma, Matsuzawa, & Scardamalia, 2016), despite the different directions they took for their Knowledge Building. Students in both classes shifted from understanding light as travelling in a straight line to light travelling in a zigzag. While the Ontario class further shifted to light travelling in a wave, it is important to note that the Ontario students spent three months studying light, whereas the Singapore students spent one month. Thus, a comparison of their learning outcomes would not be entirely fair. Given an additional two months, however, we would not be surprised that these students would reach similar levels of understanding, if not beyond.

In addition to replicating the rotating leadership phenomenon in Singapore, we extended past research by adding the teacher perspective to understand the community dynamics of Knowledge Building classrooms. In particular, the teacher noticed a shift in students' intentionality toward their learning during this intervention when they were given more autonomy, suggesting that rotating leadership taps into students' *epistemic agency* as well as *collective responsibility*. It is interesting to note that the teacher noticed different students leading during face-to-face versus online discussions. However, the discrepancy between the teacher perceptions and rotating leadership visualization suggests that student leaders facilitated the self-organization of idea improvement on Knowledge Forum, without any direct intervention by the teacher. At the same time, it is also important for the teacher to be aware of these students and their contributions. One possible explanation is that rotating leadership also taps into the KB principle of *democratizing knowledge*, making important notes and ideas transparent to all. This is especially important for bridging the gap between stronger and weaker students in the classroom. The fact that weaker students who were picked up as leaders experienced greater learning gains in the summative assessment seems to directly support the notion that learning is a byproduct of Knowledge Building (Bereiter & Scardamalia, 2010). Knowledge Building represents one way to engage all students deeply and meaningfully in the classroom through the valuing of student voice. We intend to invite student voice to further illuminate the relation between rotating leadership and collective responsibility.

References

Barab, S. (2014). Design-based research: A methodological toolkit for engineering change. In K. Sawyer (Ed.), *Cambridge Handbook of the Learning Sciences* (pp. 151-17). New York: Cambridge University Press.

Bereiter, C., & Scardamalia, M. (2010). A brief history of knowledge building. *Canadian Journal of Learning and Technology*, *36*(1). Retrieved from http://cjlt.csj.ualberta.ca/index.php/cjlt/article/view/574/276

Bereiter, C. & Scardamalia, M. (2014). Knowledge building and knowledge creation: One concept, two hills to climb. In Tan, S. C. & Tan, Y. H. (2014). *Knowledge creation in education* (pp. 35-51). Singapore: Springer.

Creswell, J. W., & Plano Clark, V. L. (2011). *Designing and Conducting Mixed Methods Research*. Thousand Oaks: Sage Publication.
Chuy, M., Resendes, M., Tarchi, C., Chen, B., Scardamalia, M., & Bereiter, C. (2011). Ways of contributing to an explanation-seeking dialogue in science and history. *QWERTY - Interdisciplinary Journal of Technology, Culture and Education*, 6(2), 242–260.
Gloor, P. A. (2006). *Swarm Creativity: Competitive Advantage through Collaborative Innovation Networks*. New York: Oxford University Press.
Gloor, P. A., Laubacher, R., Dynes, S. B., & Zhao, Y. (2003, November). Visualization of communication patterns in collaborative innovation networks-analysis of some w3c working groups. In *Proceedings of the twelfth international conference on Information and knowledge management* (pp. 56-60). ACM.
Hong, H. Y., & Sullivan, F. R. (2009). Towards an idea-centered, principle-based design approach to support learning as knowledge creation. *Educational Technology Research and Development*, *57*(5), 613-627.
Kidane, Y. H., & Gloor, P. A. (2007). Correlating temporal communication patterns of the Eclipse open source community with performance and creativity. *Computational and mathematical organization theory*, *13*(1), 17-27.
Ma, L., Matsuzawa, Y., Chen, B., & Scardamalia, M. (2016). Community knowledge, collective responsibility: The emergence of rotating leadership in three knowledge building communities. In C. K. Looi, J. Polman, U. Cress, & P. Reimann (Eds.), *Transforming Learning, Empowering Learners: The International Conference of the Learning Sciences (ICLS) 2016, Volume 1* (pp. 615-622). Singapore: The International Society of the Learning Sciences.
Ma, L., Matsuzawa, Y., & Scardamalia, M. (2016). Rotating leadership and collective responsibility in a grade 4 knowledge building classroom. *International Journal of Organizational Design and Engineering*, 4(1/2), pp. 54-84.
Ma, L. (2016). The emergence of rotating leadership for idea improvement in a grade 1 knowledge building community. In M. P. Zylka, H. Fuehres, A. Fronzetti Colladon, & P. Gloor (Eds.), *Designing Networks for Innovation and Improvisation: Proceedings of the 6th International Collaborative Innovation Networks (COINs) Conference* (pp. 13-20). Switzerland: Springer International.
Mourshed, M., Chinezi, C., & Barber, M. (2010, November). *How the world's most improved school systems keep getting better*. London: McKinsey and Company.
Nonaka, I. and Takeuchi, H. (1995) *The Knowledge-Creating Company: How Japanese Companies Create the Dynamics of Innovation*. New York: Oxford University Press.
O'Donnell, A., & Hmelo-Silver, C., (2013). What is collaborative learning?. In C. Hmelo-Silver, C. Chinn, C.K.K. Chan, & A. O'Donnell (Eds.), *The International Handbook of Collaborative Learning* (pp. 1-16). New York: Routledge/Taylor & Francis.
OECD (2010). *The OECD innovation strategy*. Paris: OECD Publishing.
Scardamalia, M. (2002). Collective cognitive responsibility for the advancement of knowledge. In B. Smith, & C. Bereiter (Eds.), *Liberal Education in a Knowledge Society* (pp. 67-98). Berkeley: Publishers Group West.
Scardamalia, M. (2004). CSILE/Knowledge Forum®. In *Education and Technology: An Encyclopedia* (pp. 183-192). Santa Barbara: ABC-CLIO.
Scardamalia, M., & Bereiter, C. (2014). Knowledge building and knowledge creation: Theory, pedagogy, and technology. In K. Sawyer (Ed.), *Cambridge Handbook of the Learning Sciences* (pp. 397-417). Cambridge University Press, New York. Tan, S. C., So, H. J., & Yeo, J. (Eds.). (2014). *Knowledge Creation in Education*. Singapore: Springer.
Singapore Ministry of Education (2013). *Science Syllabus: Lower and Upper Secondary Normal (Technical) Course*. Retrieved from https://www.moe.gov.sg/docs/default-source/document/education/syllabuses/
Zhang, J., Hong, H. Y., Scardamalia, M., Teo, C. L., & Morley, E. A. (2011). Sustaining knowledge building as a principle-based innovation at an elementary school. *The Journal of the Learning Sciences*, *20*(2), 262-307.
Zhang, J., Scardamalia, M., Reeve, R., & Messina, R. (2009). Designs for collective cognitive responsibility in knowledge-building communities. *The Journal of the Learning Sciences*, 18(1), 7-44.

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