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Knowledge Building in Robotics for Math Education

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Abstract: Competition-Based learning is the most common approach for integrating robotics into teaching activities. However, such a learning environment creates a dichotomy in which talented students are the winners at the expense of less talented students. This study aims to employ knowledge building pedagogy and technology in robotics so that no one remains at the periphery of the knowledge network. Employing COINs framework, we have analyzed the community dynamics against knowledge creation organizations. The results of the analysis show that knowledge building approach creates an open innovation community in which there are not insiders and outsiders but one where everyone can move between roles of innovator, learner, and lurker.

Introduction

Robotics education has been shown to promote problem-solving, creativity, critical thinking, collaboration and teamwork along with better understanding of Science, Technology, Engineering, and Mathematics (STEM) (e.g., Attard, 2012; Bers & Portsmore, 2005; Gura, 2012). It has been claimed that Competition Based Learning (CBL) is the most effective way to integrate robotics into subjects such as math and physics (e.g., Giannakopoulos, 2009). In CBL, students build and program robots to produce winning designs and get credit if their designs beat out others (Kanda, Shimada, & Koizumi, 2012). Studies have demonstrated that robotics competitions provide engaging contexts for learning STEM subjects and promoting students' interests toward STEM-related fields (e.g., Johnson & Londt, 2010; Welch, 2010). Hence, researchers and educators have widely employed CBL to integrate robotics into education (Altin & Pedaste, 2013; Jung, 2012).

Although the concept of competition in education is supported by several studies (e.g., Lawrence, 2004; Verhoeff, 1997), there are several concerns. It has been found that during competitive activities, communication and helping others is usually minimized because students perceive their goals as only being reached if other students fail to achieve their goals (Johnson, Johnson, & Smith, 1991). The growing emphasis on the final products of competitive activities sometimes leads students to disregard other goals such as groups' interactions, collaboration and shared visions (Cohen, Brody, & Sapon-Shevin, 2004). Therefore, competitions may "discourage active construction of knowledge and the development of talent by isolating students" (Johnson et al., 1991, p. 11) and eliminate students with less background knowledge or prior interest. In robotics competitions, like other competitive activities, it is common to have some developed projects and some projects in early stages; Hallak and colleagues (2015) state that only a few groups of students could actually complete their robots.

Knowledge building communities aim to democratize knowledge, with each student producing knowledge of value to others, and advancing community knowledge. The ultimate goal of knowledge building is to re-create schools as knowledge creation organizations (Bereiter & Scardamalia, 2006). In an attempt to provide a framework to understand dynamics of knowledge creating organizations and the contributors' behavior, Gloor (2006) analyzed innovation-intensive organizations and identified three types of collaboration networks: Collaborative Innovation Networks, Collaborative Learning Networks, and Collaborative Interest Networks. These three networks together form the ecosystem of Collaborative creation organizations which Gloor believes are "extremely powerful engine of open and disruptive innovation for knowledge creation and dissemination" (p. 136).

Collaborative Innovation Network (COIN)

A COIN is formed by the most dedicated, self-organized and intrinsically self-motivated people who have a collective vision. Although a COIN has the smallest number of members compare to other two networks, it forms the core of a knowledge creation organization. Members in this network share ideas, information, and work to achieve the common goal. The members of the COIN share "the same 'genes'" (Gloor, 2006, p. 22), because their main goal is to create innovative things, and they do their best to succeed and spread the innovation. However, it is worth noting that more than one COIN will be formed in a knowledge network, due to advancements in knowledge of people who are not members of the existing COIN. However, membership in COINs is fluid; founding members may leave the COINs due to changes in their interest.

Collaborative Learning Network (CLN)

Once a COIN is formed to create innovative ideas, other people join the community to discuss the new ideas emerging, to share common interest and common knowledge, to learn about the purpose or the applications of the proposed ideas, and to collaboratively work to develop ideas (DiMaggio, Gloor, & Passiante, 2009; Gloor, 2006). The members of this network include people who may lack the skill, time, or interest to join the COIN, but are interested in discussing the ideas emerging and the knowledge being shared (Gloor, 2006). The members of this network are "well networked into the core group [COIN]," and are instrumental in recruiting new core team members (Gloor, 2006, p. 146).

Collaborative Interest Network (CIN)

This network is formed by people with similar interests who typically "do little actual work together in a virtual team" (Gloor, 2006, p. 127). The members of this network are people who are fascinated by the core team and are connected to one or two members of the COIN as well as some members of the CLN. However, these lurkers at the periphery are "the agents of knowledge dissemination, spreading the seeds of acceptance for the new product" (Gloor, 2006, p. 188).

Each of these three networks is embedded in the subsequent, larger community. The COIN is the smallest community which is the heart of this set of concentric communities, while the CIN is the largest and outermost community. As stated by Gloor, innovations can inspire the peripheral networks, resulting in forming new COINs. During this process, a COIN attracts some peripheral people. These people at the periphery may not be necessarily interested in becoming the core COIN members, so the COIN will be expanded into a large CLN over time. Later, some people at the periphery of the CLN who are fascinated by the new innovations will expand the CLN into a CIN. However, the process does not come to an end; rather, new innovative ideas arise among members of the CIN, and a new COIN will be formed by the most dedicated members of the CIN. Gloor argued that the process of community growth and segmentation is the "incubator for new innovations," and the "major vehicle for the dissemination of innovation" (Gloor, 2006, p. 131).

Although Gloor has focused on adults working in innovation-intensive organizations, it offers an analytic framework that addresses concerns important in education at all levels. The goal of Knowledge Building is to re-create schools as knowledge creation organizations. This study aims to evaluate knowledge building classes against knowledge-creation organization criteria and to employ knowledge building pedagogy and technology in robotics, as a contrast to competition-based learning. The flow of ideas inward and outward in the network structure and the movement of individuals between circles is the focus of my research. Therefore, the research question to be addressed is: Whether the knowledge creation organizations patterns can be found in education settings?

Theoretical framework

Scardamalia (2002) and Scardamalia and Bereiter (2006) presented 12 principles that describe Knowledge Building as a principle-based pedagogy and that are set forth to make knowledge creation more accessible to teachers and students. These 12 principles frame Knowledge Building as an idea-centered pedagogy with students as epistemic agents, creating knowledge through engaging in complex socio-cognitive interactions in which students create *community knowledge*. Knowledge Building emphasizes *community* and *collective responsibility for knowledge advancement*. In such a community, students are encouraged to advance community knowledge through participation in *progressive discourse* (Beretier, 1994; Bereiter & Scardamalia, 1993) and contribute to the community knowledge and a shared knowledge objective (Bereiter, Scardamalia, Cassells, & Hewitt, 1997). In essence, in Knowledge

Building, knowledge is viewed as a social product with students taking collective responsibility for the state of public knowledge and continual idea improvement (Bereiter, 2002; Scardamalia, 2002). From a Knowledge Building perspective, the community succeeds through the distribution of group effort across all members; ideas should be made available to the community as publicly accessible artifacts that can be discussed, interconnected, revised, and superseded (Scardamalia & Bereiter, 2003). Individual interests and expertise are complemented by those of the community as each tries to achieve both individual and community goals (Amar, 2002).

The exponential growth of Web 2.0 applications has facilitated the formation of collaborative networks. The most widely recommended environment to support Knowledge Building and create collaborative networks in education settings is Knowledge Forum®—a web-based discourse medium specifically designed to support production and refinement of community knowledge to support effective action through social interaction. Knowledge Forum with its specific design provides opportunities for students to act as knowledge workers in an open space (Scardamalia, 2004) and is used in this study to establish COINs.

Method

This study explores work in mathematics (e.g., proportion, area, distance, length) using robotics and employing Knowledge Building pedagogy and technology in a Grade 5 class of 23 students. Students were asked to design a robot to deliver food, medicine, and water to refugees living in an imaginary refugee camp, designed by themselves. The students were expected to consider different mathematical concerns, including the area of the camp, the number of tents, the number of refugees in each tent, the pathways, the size and capacity of the robot, etc. They used Knowledge Forum to share their ideas, ask questions, and discuss their problems with all other students in the community. A total number of 229 notes have been posted by students over the course of two months (96 notes in the first month and 133 notes in the second month).

To address the research question, we employed social network analysis to analyze students' collaboration patterns according to knowledge creation organizations dynamics and explore whether students form the three networks identified by Gloor (2006) and whether students move from one network to the other networks. For this part, the notes posted by students in Knowledge Forum are collected and analyzed to determine who communicated with whom. SNA is employed to analyze students' interactions based on the innovation network framework (Gloor, 2006), and to identify different types of collaborative networks (i.e., COINs, CLNs, CINs) based on network parameters. The measures used in this study are betweenness centrality and density. Network density is defined as the ratio of the actual number of communication connections to the maximum potential communication connections (Degenne & Forsé, 1999). Density can be an indicator of initiating and spreading ideas; if the structure of a network allows ideas to spread, the information cascades can occur; otherwise, they cannot (Watts & Dodds, 2007). Betweenness centrality is a measure to identify the informational bridges who can control access to knowledge and can influence the direction of the discourse (Scott, 1991). As Gloor (2006) described, a central cluster in the network with high density and low group betweenness centrality forms a COIN. On the other hand, CLNs and CINs have higher group betweenness centrality and lower density, because "external members are connected only to core team members but not among themselves" (Gloor, 2006, p. 150). These parameters, along with other statistic measures like note writing are used to identify who the members of the COIN, CLN, and CIN are.

Data Analysis

Using Gephi, a Social Network Analysis tool, we have mapped the network of contributors in month 1 and month 2.

Month 1

Figure 1 shows students contribution network in the first month. According to Gloor (2006), a highly connected cluster of people is a strong indicator of the emergence of an innovation team. Considering this criterion, and according to Figure 1, the following students are the potential COIN members: Alt, Tho, Ash, Ang, and Ryd.

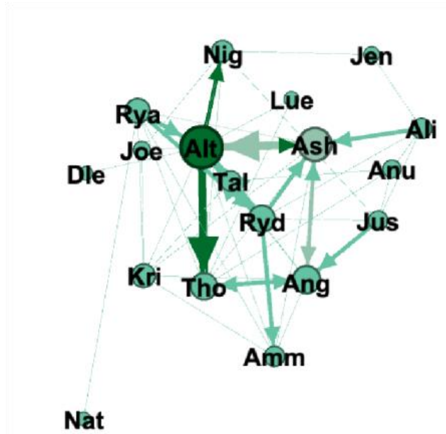

Figure 1. The network of the writers in the first month

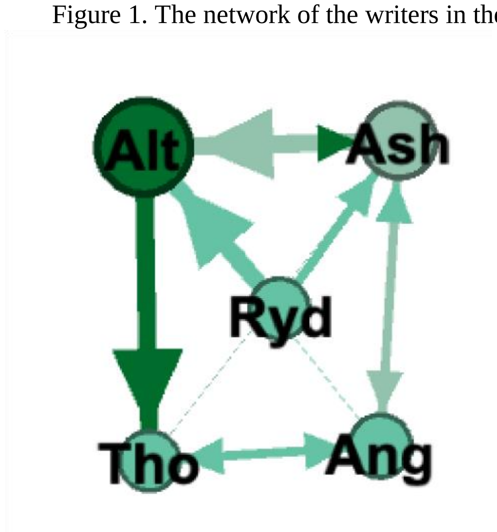

Figure 2. The COIN network

To verify the COIN members have been correctly identified, Gloor suggested conducting a social network analysis. According to Gloor, a COIN network has a high group density and low group betweenness centrality. We have conducted the social network analysis using Gephi and calculated the group density. To calculate the group betweenness centrality, we use Freeman's index for quantifying the overall level of betweenness in a set of actors BCgroup. According to Freeman's index, the group betweenness centrality can be calculated using the following equation:

$$BC_{\#\$\%\&'} = \frac{\sum_{i=1}^{g}[BC_{*} - BC_{i}]}{(N-1)} \qquad \text{Eq.1}$$

Where BC* is the largest realized normalized actor betweenness index of the set of actors and N is the number of nodes in the network. Table 1 shows the density and betweenness centrality measures for the whole network, COIN network, and CLN/CIN network. As can be seen in Table 1, the identified COIN network has the lowest group betweenness centrality and the highest group density, which shows the COIN and CLN/CIN networks have been correctly identified.

Table 1. Density and group betweenness centrality of the networks

Network	Density	GBC
Whole network	0.163	---
COIN	0.55	0.03168158
CLN/CIN	0.086	0.16391732

Figure 3 shows the people who form the CLN and CIN.

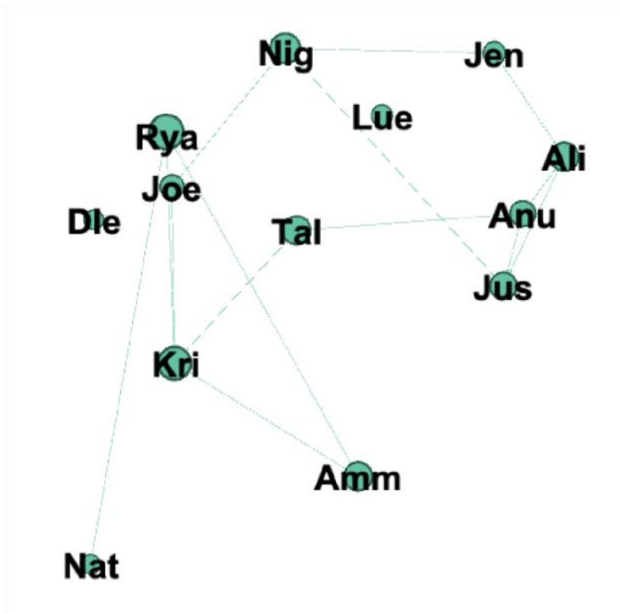

Figure 3. CLN and CIN members

As stated by Gloor (2006), the CLN members -like experts- actively share knowledge. On the other hand, while a minority of people in a CIN share knowledge, the majority of them are silent knowledge seekers (lurkers) who do not usually contribute any content (Gloor, 2006). Therefore, students who have posted a reasonable number of notes (i.e., above the average) form the CLN. To identify the members of each CLN and CIN, the log data are used (Figure 5.14 and 5.15). As can be seen in Figure 4, Rya, Kri, Ali, Amm, Nig, Tal, Anu, and Lue have posted notes more than the average number of notes posted by the CLN and CIN members. Therefore, they form a CLN network, while other students form a CIN network.

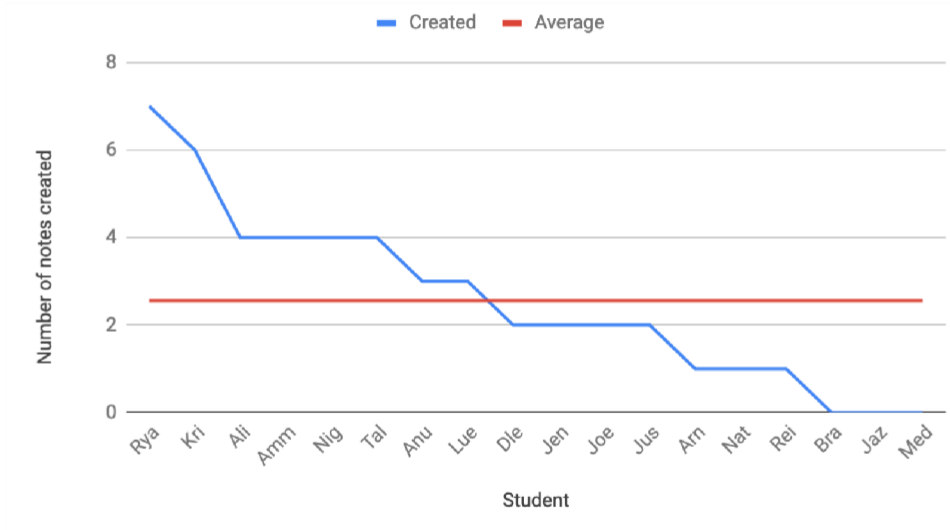

Figure 4. The number of notes created by the CLN and CIN members

Month 2

We have followed the same procedure to identify COIN, CLN, and CIN in the second month. Figure 5 shows the network of the contributions. As it is evident in Figure 5, Alt, Rya, Kri, Amm, and Ash form a central dense cluster. Therefore, they potentially can form the COIN network.

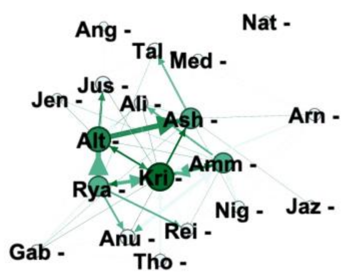

Figure 5. The network of the writers in the second month

We analyzed this subgroup and calculated the graph density and the group betweenness centrality of each network (i.e., COIN and CLN/CIN). Table 2 shows the results of this analysis.

Table 2. Density and group betweenness centrality of the networks

Network	Density	GBC
Whole network	0.278	---
COIN	0.65	0.0310125
CLN/CIN	0.077	0.189827056

As Table 2. shows, the identified COIN has the highest density and the lowest group betweenness centrality, which confirms the COIN networks has been correctly identified. Also, the CLN/CIN network has the lowest density and the highest group betweenness centrality, showing that they form the CLN/CIN network.

To identify the members of the CLN and CIN, as stated before, the log data are used. Using the writing note logs data (Figure 6), it is evident that Anu, Ali, Arn, Jus, Rei, Gab, Nig, Tal, and Tho posted notes more than the average number of notes posted by all the CLN/CIN members. Therefore, these students are considered as the CLN members. As a result, the remaining students are the members of the CIN network.

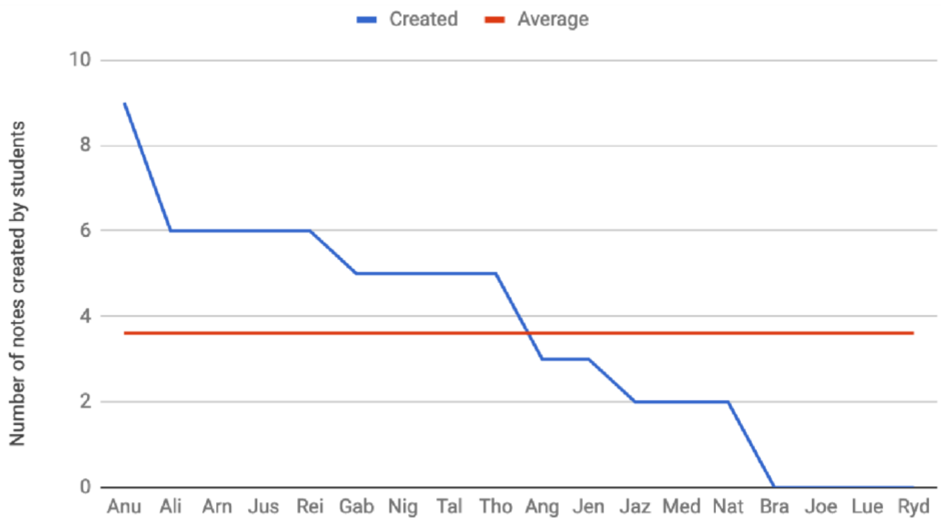

Figure 6. The number of notes created by the CLN and CIN members

Comparing the COIN members of the two formed COINs, it is evident that over time, students moved from one network to the other network. In the first view, Alt, Tho, Ash, Ang, and Ryd formed the COIN network as they are highly connected to each other. However, in the second view, Amm, Kri, Rya, Alt, and Ash formed the COIN network. Therefore, Rya, Amm and Kri have joined the initial COIN team; These students were initially members of the CLN. However, Ryd, Tho and Ang have moved to other networks. Moreover, while Jen, Dle, Joe, Nat, Bra, Jaz, and Med remained at the CIN network, Jus, Arn, and Rei moved from the CIN to the CLN network.

Discussion and conclusion

This study was the first attempt to analyze knowledge building environments in education settings against innovation network (COIN) criteria. The results of the study confirm the formation of COINs which are, according to Gloor, the "most productive engines of innovation ever" (p. 10). They provide opportunities for any organization to become a more creative, productive, and efficient organization. The results also confirm the existence of CLNs and CINs in knowledge building communities and the movement of individuals between networks, with lurkers at one point becoming learners and key innovators at another. This finding is in line with Lave and Wenger (1991)'s description of *Legitimate Peripheral Participation (LPP)* in CoP theory. As Lave and Wenger stated, learning in a CoP is like an apprenticeship model, called *LPP*, in which newcomers enter the community from the periphery and move toward the center as they become more and more knowledgeable. The results provide a framework for knowledge building researchers and teachers to examine if the work students are doing is a genuine knowledge building work; if the teachers and the researchers find these patterns, it is a genuine knowledge building work; otherwise, it is not.

The movement of the individuals from the CIN and CLN to the COIN network indicates that employing knowledge building in robotics can provide opportunities for students to learn from the talented students, improve their knowledge, and become innovators in their community. In fact, while competition-based learning in robotics results in having some students at the periphery of the knowledge network, knowledge building in robotics results in improving students' knowledge and providing opportunities for them to move to the center of the knowledge network and become innovators.

As stated by Gloor, not only the networks can be extended, but also innovation dissemination follows the ripple effect rule; innovations ripple from the most innovative network (COIN) to the next two larger circles, until they reach the rest of the virtual -and finally the real- world (Gloor, 2006). In this study, the social network analysis confirmed the network expansions, which can be an indicator of innovation dissemination. However, for the future direction, we plan to conduct a lexical analysis and examine whether the knowledge and innovation rippled from the COIN to the other networks.

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