Scaffolding Computational-Thinking Moves for Collective Knowledge Advancement in Multidisciplinary Collaboration

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Abstract: A knowledge-building environment mediated by Knowledge Forum® (KF) and enriched with students' computational-thinking moves to advance collective knowledge was examined. Thirteen multidisciplinary higher education students studying *Education and Modern Technology* participated and worked in opportunistic groups. After engaging in collective inquiries, they constructed computational-thinking moves, which were put on KF for visualization and shared inquiry. These moves were adapted as scaffolds, followed by the formulation of Idea-Friend Maps based on learning analytics. Quantitative analyses show collective knowledge advancement and changing trajectories over time. Qualitative analyses reveal how students advanced collective knowledge with computational-thinking moves in multidisciplinary collaboration. This study offers insights into developing computational-thinking competencies through learning analytics and sheds light on the use of students' explicit computational-thinking moves as scaffolds to advance collective knowledge.

Introduction

Breakthroughs in education require capabilities and challenges that emerge from efforts to engage students in authentic knowledge creation. Computational thinking has been linked to creativity and innovation (Repenning et al., 2015). According to Wing (2006), computational thinking does not mean thinking like a computer but rather engaging in problem reformulation, recursion, problem decomposition, abstraction, and systematic testing for the purpose of solving problems efficiently and creatively. Computational thinking is also considered a necessary skill for every student. Thus, approaches to cultivating computational thinking literacy have become a hot research topic. However, much of the focus is put on K-12 education by programming (Czerkawski & Lyman, 2015), and the response to Wing's call for broader applications of computational thinking has been more scattered.

Knowledge building is a major model that aims to facilitate education transformation by introducing the concept of knowledge-creating communities (Scardamalia & Bereiter, 2014). In such a community, the core work is producing new knowledge, artifacts, and ideas of value to the community. Thus, the knowledge-building environment might be a promising learning community to cultivate computational-thinking skills. Our previous studies designed external representations of KBDeX (Oshima et al., 2012), called Idea-Friend Maps, to promote primary students' science learning (Feng et al., 2020). The knowledge building-level Idea-Friend Maps were formulated to visualize boundaries of collective ideas under the inspiration of the computational-thinking component "abstraction (e.g., classification)" (Shute et al., 2017). However, the visualized ideas in different categories were pre-classified (i.e., coding) by the teacher rather than the students. Herein, the computational thinking-level Idea-Friend Maps were refined for higher education students to visualize both computational-thinking moves and their categories (i.e., coding of computational-thinking components).

Thus, the present research project combined the two constructs of computational thinking and knowledge building in a multidisciplinary environment. The research questions are (1) Did students advance collective knowledge over time, and what were the different trajectories among students? (2) How did students engage in the multidisciplinary knowledge-building environment towards collective knowledge advancement scaffolded by progressively improved computational-thinking moves?

Methods

Participants

Thirteen STEM students across several majors and grades from a science and engineering university in Shenzhen, Mainland China, participated in this project.

Design of knowledge building and Idea-Friend Maps

The enrolled participants conducted a six-week collective inquiry on a liberal arts topic, *Education and Modern Technology* on KF. In Phase 1 (Weeks 1-2), students conducted the preliminary exploration of *Educational Environment and Technology* on KF. In Phase 2 (Weeks 2-4), they further explored *Technology and Educational Transformation* on KF. Moreover, each developed a computational-thinking model placed on KF for visualization and shared inquiry. Students' preliminary and refined computational-thinking moves were adapted into KF scaffolds (Figure 1). In Phase 3 (Weeks 5-6), students engaged in opportunistic collaboration on KF with the improved computational-thinking moves enriched with learning analytics. Specifically, the computational-thinking level Idea-Friend Maps were developed as representations of KBDeX to support students' improvement of computational-thinking competencies (Figure 2). Students' computational-thinking moves, keywords, and relative codes were input to KBDeX, as shown in Figure 2. The red and yellow circles indicate keywords and codes having or having not been used by the student, respectively.

Figure 1

Regular KF scaffolds (a); student computational-thinking moves made into KF scaffolds (b)

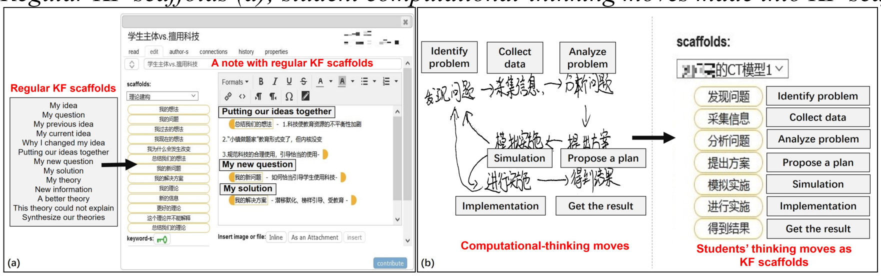
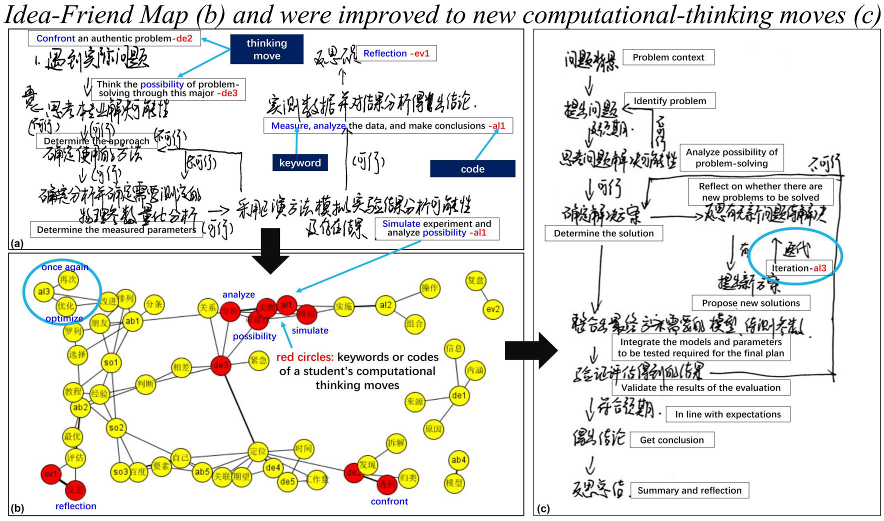


Figure 2

A student's preliminary computational-thinking moves (a) were visualized as red circles in the Idea-Friend Map (b) and were improved to new computational-thinking moves (c)



Note. *Decomposition*: *de1* = analyze the source of the problem; *de2* = identify the problem; *de3* = analyze the possibility of problem-solving; *de4* = analyze expected results; *de5* = develop a problem-solving plan. *Abstraction*: *ab1* = classification; *ab2* = comparison; *ab3* = synthesis; *ab4* = modeling; *ab5* = correlation. *Algorithm*: *al1* = simulation; *al2* = implementation; *al3* = iteration. *Evaluation*: *ev1* = reflect on weakness of the solution; *ev2* = review the process. *Generalization* (ge). *Social Interaction*: *so1* = interact with others; *so2* = seek authoritative materials; *so3* = independent.

Students first identified codes in yellow circles using the computational thinking-level Idea-Friend Maps. They then went to other students' computational-thinking moves that included those codes, which facilitated their comparison and refined computational-thinking moves. The Idea-Friend Map provides multiple sources or representations to visualize the rich complexity of all computational-thinking moves. Visualizing keywords and codes of such moves on the same interface allowed students to compare their moves with others. These Idea-Friend Maps are placed on KF for inquiry.

Data source

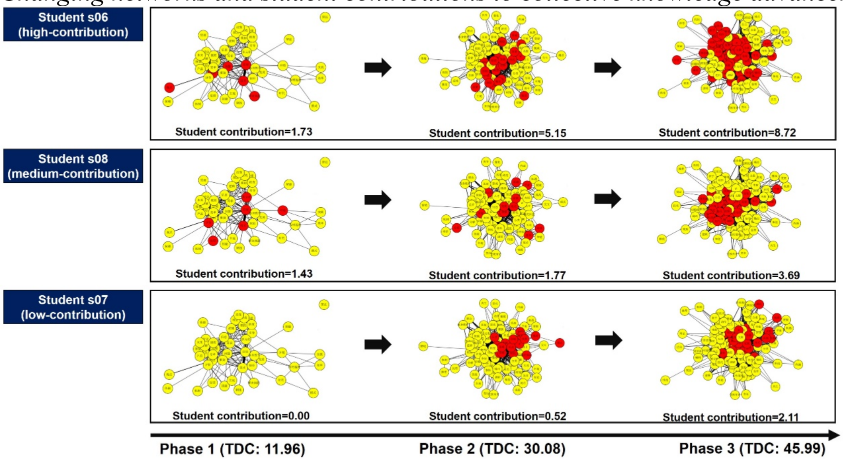
Data sources include KF writings and views, videos of classroom discourse, and knowledge artifacts.

Results

RQ1: Did students advance collective knowledge over time, and what were the different trajectories among students?

Based on knowledge-building research on KBDeX (Oshima et al., 2012), the higher the Total Degree Centrality (TDC), the denser the network of domain keywords and discourse, and the more the collective knowledge advancement (Oshima et al., 2017). KBDeX word networks can be used to track how groups evolved in their collective KF work across phases and studies. Figure 3 shows the changing word networks of different contributing students exported from KBDeX across phases. The upward trend in the TDC and network density suggests student advancement in the collective knowledge of *Education and Modern Technology* over time.

Figure 3
Changing networks and student contributions to collective knowledge advancement over phases



Furthermore, we identified three contributing students (i.e., high, medium, and low) and tracked their trajectories across phases. High/medium/low-contribution student refers to the extent to which his/her KF notes added value to the TDC of the whole class. Without any structured computational-thinking moves in Phase 1, the high and medium-contribution students presented centralized networks of red circles, demonstrating the ability to solve problems from varying subtopics. In contrast, the low-contribution student showed no red circle, indicating a poor ability to identify key ideas from the community. In Phase 2, with the preliminary structured computational-thinking moves, the high-contribution student tripled the contribution to collective knowledge advancement compared with Phase 1, while the medium-contribution student just increased about one quarter. However, the low-contribution one displayed its contribution, which was less than one-tenth of the high-contribution group. In Phase 3, with the support of the improved computational-thinking moves, the high and medium-contribution students doubled their contribution compared with Phase 2, while the low-contribution one even quadrupled. These results suggest the role of the structured computational-thinking moves in scaffolding students with different contributions for collective knowledge advancement.

RQ2: How did students engage in the multidisciplinary knowledge-building environment towards collective knowledge advancement scaffolded by progressively improved computational-thinking moves?

Theme 1. Transferring daily problem-solving moves to individual computational-thinking moves

Combined with daily problem-solving examples, students framed their computational-thinking moves. For instance, student s08 majoring in earth and space physics, took examples from his academic area and structured computational thinking with such moves as “Think about the possibility of problem-solving through this major” and “reflection” (Figure 2a).

Theme 2. Adopting individuals’ computational-thinking moves as KF scaffolds to solve KF problems

The teacher and students adapted those moves as KF scaffolds to better visualize peers’ computational-thinking moves. Afterward, students utilized their or peers’ thinking moves to solve identified problems. For instance, student s06 adopted s03’s thinking moves to frame the definition of technology, educational transformation, and relationships. Then student s12, with his computational-thinking moves, built on the note from student s06 and further identified the symbiotic relationship between technology and educational transformation.

Theme 3. Improving individuals’ computational-thinking moves through boundary-crossing with the support of Idea-Friend Maps

To improve individuals’ computational-thinking moves, the teacher and students adopted the designed Idea-Friend Maps, which visualized boundaries of computational-thinking moves’ keywords and codes. For instance, student s08 found the yellow circle of the code *al3* (i.e., iteration) that he did not have. Then student s08 reviewed student s01’s thinking moves and brought “iteration” as a boundary in his improved computational-thinking moves (see blue circles in Figure 2b and Figure 2c).

Theme 4. Conducting opportunistic collaboration to work at the cutting edge with the improved computational-thinking moves

After transforming the improved computational-thinking moves into KF scaffolds, students worked as opportunistic groups to develop promising ideas for the community, focusing on (1) the induction training for employees of high-tech enterprises; (2) evaluation of science and technology education products; (3) efficiency evaluation of K-12 exercise class; and (4) application of immersive learning through VR technology in Taekwondo classroom. For instance, one group utilized such computational-thinking moves as "decomposition," "review and summary," and "generalization" to work on the cutting edge of induction training.

Theme 5. Reflecting how collective knowledge was advanced with the progressively improved computational-thinking moves

Students reflected on the improvement of computational-thinking moves and collective knowledge advancement in multidisciplinary collaboration. For example, student s07 identified three phases for the developmental trajectory of collective knowledge advancement, specifically, from exploring the way of computational thinking to identifying promising ideas in the community, and finally to progressive knowledge building with the support of computational-thinking moves. These results suggest how computational-thinking moves scaffolded and enriched students in collective and individual knowledge advancement.

Conclusion

Most computational-thinking studies linked programming skills while less attention was paid to computational thinking skills as a broader goal of solving problems efficiently and creatively. Differently, this study developed a multidisciplinary environment for students to collaborate with peers' computational-thinking moves with the support of learning analytics (i.e., Idea-Friend Maps) in the knowledge-building environment. Furthermore, when knowledge-building studies are typically focused on how collective ideas were developed in a single-disciplinary community, this study is one of the few studies embedding specialized thinking for authentic knowledge creation in multidisciplinary environment. Moreover, under the computational thinking-level Idea-Friend Maps visualizing collective thinking moves and corresponding codes, students could improve their computational-thinking moves and use them as KF scaffolds for the advancement of collective knowledge. Further inquiry into how trajectories of knowledge-building designs for promoting students' computational thinking and creative problem-solving abilities will be conducted.

Acknowledgement

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