Co-designing a Collective Journey of Knowledge Creation With Idea-Friend Maps

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Abstract: We examined a knowledge building environment, mediated by Knowledge Forum®, in which representations from a learning analytics tool were used for creating "Idea-Friend Maps", to scaffold knowledge creation. Fifty-two Grade Five students studying *Human Input & Output* participated and worked in 12 groups. Quantitative analysis of Knowledge Forum notes shows that students' contribution to collective knowledge advancement significantly predicted students' science scores. By examining analytics-based pivotal turns, centralities, and knowledge building discourse moves, this analysis reveals different patterns of knowledge building trajectories among high-, medium-, and low-contribution groups, as well as the role of Idea-Friend Maps in scaffolding collective knowledge creation. We also examined how students co-designed and used the collective journey to sustain their knowledge creation, with the aid of Idea-Friend Maps. This study sheds light on using opportunistic groups and learning analytics approach to examine and to scaffold student knowledge building trajectories in collective inquiry and ways of fostering collective knowledge creation in large communities.

Introduction

Education is facing challenges in equipping learners with capacities for knowledge creation and innovation(OECD, 2017). The *Knowledge Building* (KB) approach, created and developed by Bereiter and Scardamalia based on decades of research, is an essential model in the learning sciences (Bereiter & Scardamalia, 1993). As a social construction theory and pedagogy, it aims to bring a fundamental transformation to education by introducing the conception of knowledge-creating communities (Scardamalia & Bereiter, 2014). In the computer-supported collaborative learning environment, Knowledge Forum (KF) was designed for creative community work. KF allows knowledge workers to post problems, propose explanations, test ideas, rise above, achieve collective advances, and conduct a sustained pursuit of inquiry (Scardamalia, 2002).

KB has been widely carried out with variations in countries, grades, subjects, and backgrounds (Chen & Hong, 2016). Due to concerns over the volume of writings produced by a class and the students' response capacity, teachers usually assign students to small groups on KF. However, this approach has its limitations (e.g., idea diversity). In a 3-year design study, Zhang, Scardamalia, Reeve, and Messina (2009) examined different social configurations, including *fixed groups* (students working in fixed groups), *interactive groups* (students working in fixed groups but also carrying out cross-group activities), and *opportunistic groups* (students working temporarily in groups formulated by interests), finding that *opportunistic groups* yielded the best learning outcomes. Unlike the majority of KB studies focusing on small communities of around 15 to 30 students, we explored KB in larger communities. To figure out whether opportunistic interaction (Zhang et al., 2009) is a useful strategy for KB in large communities is of great importance to the uptake of KB in many Asian countries, where large classes of 50 to 60 students are common.

There are other practices involving using learning analytics to structure the changing status of collective knowledge in KB. The numerous online notes generated by large classes with large datasets also provide opportunities for studying analytics (Baker & Inventado, 2014). A good deal of research has analyzed the changing social networks of *student*, *word,* and *discourse* by KBDex (Oshima, Oshima, & Matsuzawa, 2012). Although KBDex is used widely in research assessments (Ma, Tan, Teo, & Kamsan, 2017; Oshima, Ohsaki, Yamada, & Oshima, 2017) and teachers' professional development (Teo, Chan, & Ng, 2018), little attention is paid to the application of KBDex by students. Therefore, we designed external representations of KBDex for promoting science learning among Grade Five students. Idea-Friend Maps (IFMs) were used as external representations of KBDex. And the IFM environment was designed and tested combined with different social configurations: a group-level IFM for interacting groups and a community-level IFM for opportunistic groups. The results demonstrated the effectiveness of IFM in boosting collective knowledge advancement (Feng, van Aalst, Chan, & Yang, 2019). Yet, results also showed that after acquiring most of the collective knowledge with the support of IFMs, students were hard to work at the cutting edge and create new knowledge (Feng, van Aalst, & Chan, 2020). Therefore, it is urgent to co-design a collective journey of knowledge creation to promote collective knowledge advancement and sustained knowledge creation. To fill this gap, we designed a knowledge creation-level IFM, as well as a collective journey of knowledge creation in this study.

The research questions are:

(1) What were the effects of the IFMs environment on students' conceptual growth and collective contribution, and did their engagement in collective contribution predict conceptual understanding?

(2) What were the developmental patterns of students' collective knowledge advancement in the IFMs environment for different contributing groups?

(3) How did students co-design and use the collective journey to support their sustained knowledge creation, with the aid of IFMs?

Methods

Participants

Fifty-two Grade Five students from a primary school in China were enrolled and divided into 12 groups with 4-5 students for each group. The first author served as their science teacher.

Pedagogical design

A collective inquiry of *Human Input & Output* was carried out for nine weeks. Students used KF as an online platform to post problems, propose explanations, and to sustain their pursuit of collective inquiry (Figure 1). In Phase 1 (Weeks 1-3), students, supported by group-level IFM (Figure 1(b) and Figure 2(a)), interacted with 8 science domain views (subtopics) of *Food Input*, *Excreta Output*, *Gas Input*, *Gas Output, Digestive System*, *Respiratory System*, *Cardiovascular System* and *Others* (Figure 1(a)). In Phase 2 (Weeks 4-6), assisted by the community-level IFM (Figure 1(c) and Figure 2(b)), they identified key problems of the community and bridged knowledge/synthesized in opportunistic groups on the *Community Building* view (Figure 1(c)). Following is the reflection on their KB learning journey and comparison with how scientists work, so the collective knowledge creation journey can be designed. In Phase 3 (Weeks 7-9), based on the designed journey, more profound opportunistic activities were promoted, facilitating students to put forward theories (Figure 1(e)), find out evidence (Figure 5(d)), and come to conclusions. Eventually, under the knowledge creation-level IFM (Figure 1(e) and Figure 2(c)), they conducted sustained inquiries on the collective knowledge creation views (Figure 1(d)).

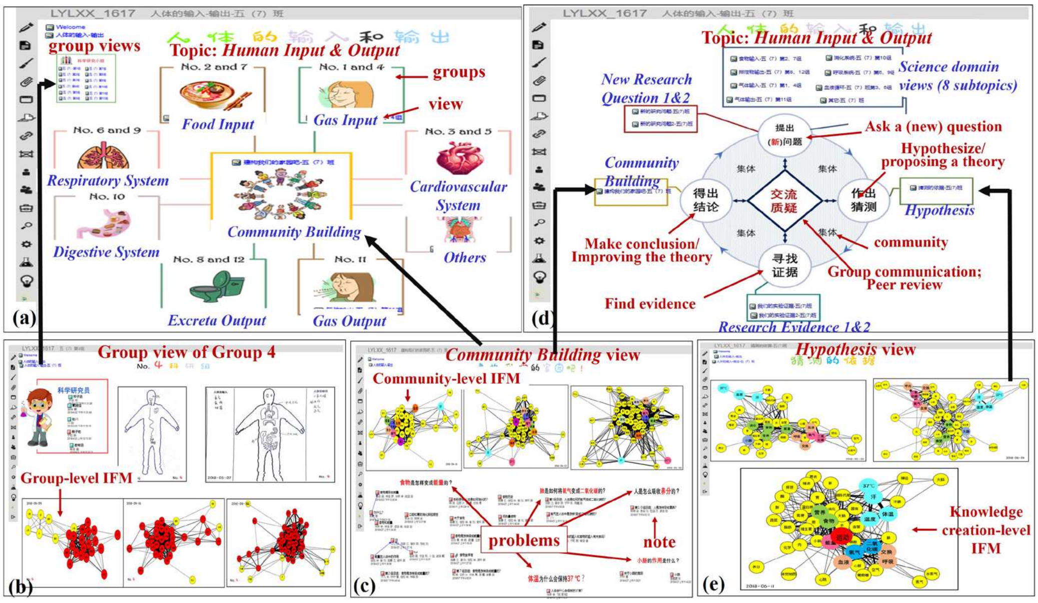

Figure 1. The science domain views and the *Community Building* view (a); the group view of Group 4 (b); the *Community Building* view (c); the collective knowledge creation views (d); the *Hypothesis* view (e).

The learning analytics tool (Idea-Friend Maps)

KBDex is a novel learning analytics tool that generates three types of networks, with students, keywords, and discourse (notes) on KF as the node (Oshima et al., 2012). The word network exported from KBDex is the designed IFMs. A group-level IFM (Figure 2a) to support the interactive activities in Phase 1, a community-level

IFM (Figure 2b) to promote opportunistic interactions in Phase 2, and a knowledge creation-level IFM (Figure 2c) to promote collective knowledge creation in Phase 3 were designed. Figure 2(a) depicts a group-level IFM, where red balls and yellow balls denote those keywords having already been and not been discussed by the group respectively. Among them, yellow balls near the red ones represent "idea friends" (the "friendships" are among ideas), analogous to the proximity of scientific ideas in research. Students in this group first identified "small intestine" as an idea friend of "food", and then moved to the *Digestive System* for relevant information. Figure 2(b) shows a community-level IFM, in which those key problems identified in the *Community Building* view are denoted by colored balls (except yellow ones). For instance, the pink ball "nutrient" represents the key problem "How do people absorb nutrients?". It can be synthesized by students in opportunistic groupings according to the surrounding yellow balls. Figure 2(c) displays the newly designed knowledge creation-level IFM: balls with the same color (except yellow ones) indicate key ideas identified in the same problem. For instance, a new problem "Why do we sweat after exercise but lose our body temperature?" was put forward by the connection between the red ball "exercise" and light blue balls denoting "sweat", "temperature" and "37°C". In this way, students can identify key problems in each subtopic, find gaps among problems, make further sustained inquiries, put forward hypotheses and seek for collaborative groups to eventually promote collective knowledge creation like scientists.

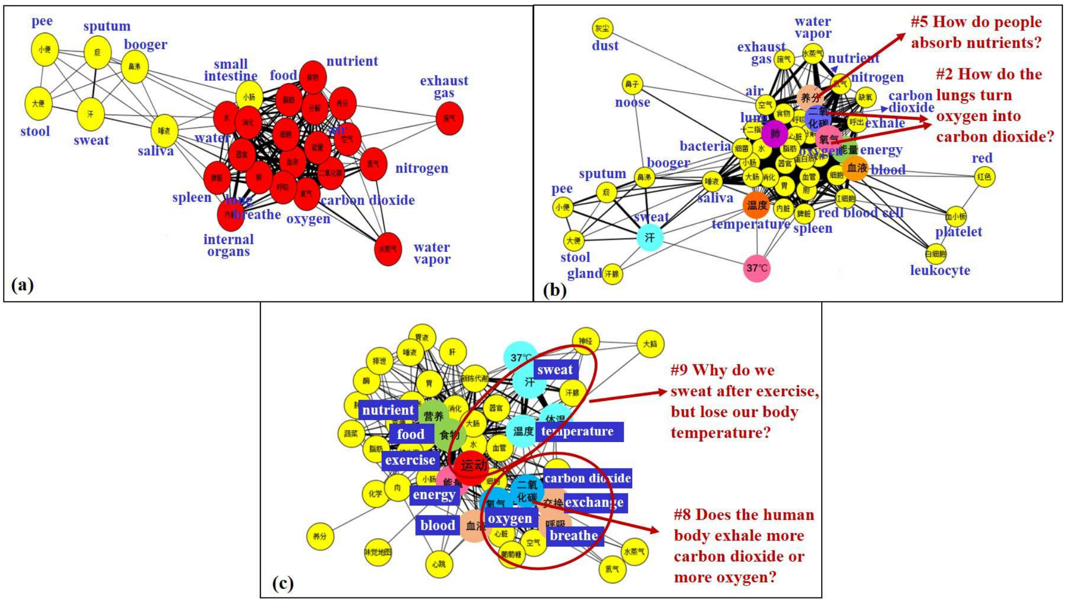

Figure 2. The IFMs: a group-level IFM (a); a community-level IFM (b); a knowledge creation-level IFM (c).

Data sources

The data sources involve (1) 430 KF notes, (2) 8 science domain views, 6 collective knowledge creation views and 12 group views, (3) students' pretest and posttest scores, (4) videos of classroom discourse, (5) students' artifacts.

Data analysis and findings

RQ1: What were the effects of the IFMs environment on students' conceptual growth and collective contribution, and did their engagement in collective contribution predict conceptual understanding?

Changes in conceptual understanding

Results from a paired-samples t-test showed significant differences between students' pretest scores of science learning (M = 48.79, SD = 9.93) and their posttest scores (M = 74.13, SD = 12.61), $t(47) = 13.90$, $p < .001$. The results suggest that students obtained higher scores at posttest with their experience in the IFM environment.

Changes in student contribution to collective knowledge advancement

Oshima et al. (2012) assessed collective knowledge advancement through Total Degree Centrality (TDC), which was adopted in this study. In this case, *Note Contribution* is defined as the contribution of the note to collective knowledge advancement and calculated as the difference in TDC between the current and the previous KF discourse (note) network. Then, the author of each note was identified to calculate each student's contribution to collective knowledge advancement.

Afterward, using paired-samples t-tests, we examined the differences in students' collective contribution across Phase 1 & 2 & 3. Students contributed more to collective knowledge advancement over time. Significant difference was found between Phase 1 (M = 0.82, SD = 1.71) and Phase 2 (M = 1.19, SD = 1.82), $t(51) = 5.89$, $p < .001$, and also between Phase 2 and Phase 3 (M = 1.30, SD = 1.83), $t(51) = 6.01$, $p < .001$. These results suggest that under different levels of IFMs across phases, students' contribution to collective knowledge advancement increased over time.

Prediction of conceptual understanding

Hierarchical regression was employed to explore the predictors of conceptual understanding. Results show that students' pretest scores of science learning could predict their posttest scores, as in $R^2 = .15$, $F(1, 46) = 8.30$, $p < .01$. More specifically, when students' contribution to collective knowledge advancement were entered, an additional 13% of the total variance was explained, as in $R^2 = .28$, $F(2, 45) = 8.83$, $p < .01$, indicating that students' contribution to collective knowledge can predict their conceptual understanding.

RQ2. What were the developmental patterns of students' collective knowledge advancement in the IFMs environment for different contributing groups?

To explore patterns of collective knowledge advancement throughout the phases, we analyzed group participation in different views and KB discourse moves of the pivotal notes (Figure 3). The pivotal note denotes a group's highest contribution to collective knowledge advancement in the current week. For instance, note #125 is a pivotal note of Group 4 in Week 1 (Table 1), and a *Community-bridging knowledge* note in the *Respiratory System* view (Figure 3).

Take Group 4 (the highest contribution group) as an example (Table 1 and Figure 3), which took responsibility for *Gas Input*. Students in this group went to the *Respiratory System* view to explore "the nature of oxygen" by *bridging knowledge* from authoritative information in Week 1 and then explained "the role of lung" in the *Gas Input* view in Week 2; they explored "the role of the small intestine" in the *Community Building* view in Week 4, selected and *synthesized* valuable notes for their research problem in the same view in Week 5, then conducted a *sustained inquiry* "Does the gas input relate to the food input?"; in Week 7, they questioned on *Experiment 11* (Table 2) in the *Research Evidence 1* view, and pointed out the incomplete evidence in that experiment; in the final week, they first conducted a *sustained inquiry* of "the relationship between the amount of oxygen exhaled and exercise" and then moved forward to a new theory, in the view of *New Research Question 1*. The above findings demonstrate how students in the highest contribution group achieved collective knowledge advancement.

Table 1: Pivotal notes' contents of Group 4 in each week

Week	Note No.	Note content
1	#125	*[New information]* Oxygen is a volatile gas. 1) Oxygen can be directly combined with other elements to form oxides. 2) Oxygen is necessary for combustion and biological respiration…
2	#168	*[My theory]* Lung is the organ that circulates air in the human body. It delivers oxygen to every part of the body, bringing nutrients; and expelling unwanted gases and purified carbon dioxide.
4	#355	*[New information]* The small intestine is the main organ for digesting food to absorb nutrients. It is about 5~6m long and has some digestive juices such as intestinal fluid…
5	#371	*[Putting our theories together]* The following note shows the travel of gas in the human body that will help our research. "*Oxygen can produce energy for the human body. The carbon dioxide produced from the reaction combines with the blood to return to the lung through the vein and is exhaled from the human body. ("Why do people need oxygen?" by c722)*" *[My new question]* Does the gas input relate to the food input?
7	#395	*[My doubt]* When a person is in a non-exercise state like sleeping, the amount of oxygen required by the human body is reduced, and then the amount of carbon dioxide emitted is also reduced. Sleeping is also non-exercise, so the data in the experiment is not comprehensive.
9	#415	*[My new question]* What is the relationship between the amount of oxygen exhaled and exercise? *[My theory]* People need more oxygen to generate energy when they exercise, so the amount of oxygen exhaled after exercise decreases, but carbon dioxide increases.

Next, we compared high/medium/low-contribution groups. In general, the high/medium/low-contribution groups all showed a progressing trend of *Questioning*, *Theorizing,* and *Community* over time. All groups focused on the science domain views in Phase 1, explored in the *Community Building* view in Phase 2, and focused on collective knowledge creation views in Phase 3. To be more specific, in Phase 1, with the group-level IFM, high/medium-contribution groups conducted KB discourse moves, including *Questioning-sustained inquiry, Theorizing-improving an explanation*, and *Community-bridging knowledge/synthesis*; while the low-contribution group just applied lower-level *Theorizing*, such as *simple claim* and *proposing an explanation*. With the community-level IFM in Phase 2 and the knowledge creation-level IFM in Phase 3, most groups shared the same pathways: *Community-bridging knowledge→ Community-synthesis→ Questioning-sustained inquiry*, and *Community-lending support→ Community-synthesis→ Questioning-sustained inquiry→ Theorizing-proposing an explanation*, respectively. In summary, students conducted knowledge bridging in Phase 1, engaged in synthesis and sustained inquiry in Phase 2, and persisted in lending support and identifying new research problems for the community in Phase 3. These findings suggested the roles of IFMs in scaffolding KB.

Notes: Different levels of KB discourse moves: *Questioning*: Q1= *fact seeking;* Q2= *explanation seeking;* Q3= *sustained inquiry. Theorizing:* T1= *simple claim;* T2= *proposing an explanation;* T3= *supporting an explanation;* T4= *improving an explanation. Community:* C1= *bridging knowledge;* C2= *synthesis;* C3= *lending support.*

Figure 3. KB discourse moves in different KF views across weeks.

RQ3. How did students co-design and use the collective journey to support their sustained knowledge creation, with the aid of IFMs?

Qualitative analysis of rich data (videos of classroom discourse, students' artifacts, KF views, and KF notes) identified five themes of how students co-designed and used the collective journey of knowledge creation.

Theme 1. Forming research groups and establishing research directions

After posting questions and ideas about the area of *Human Input & Output* on KF, students conducted a classroom discussion to determine the criteria for categorizing those KF notes – the mechanism of how systems in the human body turn inputs into outputs. Thus, all their KF notes were classified into three categories: input, human body systems, and output, including 8 subtopics: *Food/Gas Input*; *Digestive System*, *Respiratory System*, and *Cardiovascular System*; *Excreta/Gas Output* and *Others*. Then, students formed into 12 research groups with 4-5 students in each and selected research topics based on interests (Figure 1(a)).

Theme 2. Establishing group attachments and conceptualizing key ideas in *Human Input & Output* area

To recognize key ideas that other groups focused on, students worked in interactive groups on identified idea friends (yellow balls) on the group-level IFM (Figure 2(a)), then established group attachments using *Community-bridging knowledge* from authoritative information. It is a process of turning idea friends (yellow balls) into the group ideas (red balls) and understanding the entire area of *Human Input & Output* by continually exploring the key ideas from other groups.

Theme 3. Identifying and seeking answers to key questions in *Human Input & Output* area

After acquiring a general understanding of the entire area of *Human Input & Output*, students identified 7 key problems (Table 2, Problems #1 to #7). Supported by the community-level IFM (Figure 2(b)), students worked in opportunistic groups and employed *Community-bridging knowledge/synthesis* to synthesize theories. It would help them explain those key problems (colorful balls) (Table 1, Problems #1 to #4). For instance, students of Group 4, bridged knowledge to explain "the role of the small intestine" in Week 4 and synthesized theories of "how lungs turn oxygen into carbon dioxide" in Week 5. More details of this process can be found in RQ2.

Table 2. Key problems and evidences

Key problem	Evidence
#1 What is the small intestine's role?	Knowledge bridged by Group 4. (Table 1: Group 4's pivotal note #355 in Week 4)
#2 How do the lungs turn oxygen into carbon dioxide?	Theory synthesized by Group 1 and Group 4 (Table 1: Group 4's pivotal note # 371 in Week 5)
#3 Why does sweat rise when the temperature rises?	Theory synthesized by Group 8.
#4 What is the relationship between blood circulation and gas exchange?	Theory synthesized by Group 3 and Group 5.
#5 How do people absorb nutrients?	*Experiment 1:* Comparing the digestion in the oral cavity and stomach *Experiment 2:* Exploring the digestive effects of different enzymes *Experiment 3:* Exploring the digestive enzymes for breakfast/ lunch *Experiment 4:* Exploring the composition of "feces"
#6 How does food become energy?	*Experiment 5:* Using the temperature sensor to examine whether food combustion releases energy *Experiment 6:* Using oxygen and carbon dioxide sensors to identify the products of food energy-releasing *Experiment 7:* Using oxygen and carbon dioxide sensors to identify the "digestion" products of food in the human body
#7 Why does body temperature stay at 37 °C?	*Experiment 8:* Using the temperature sensor to explore the mystery of human body maintaining 37 °C
#8 Does the human body exhale more carbon dioxide or more oxygen?	*Experiment 9:* Using oxygen and carbon dioxide sensors to compare the exhaled proportions of oxygen and carbon dioxide
#9 Why do we sweat after exercise, but lose our body temperature?	*Experiment 10:* Using the temperature sensor to compare changes in body temperature before and after sweating
#10 What is the relationship between the heart & respiration rate?	*Experiment 11:* Using pulse rate and respiration sensors to explore the relationship between pulse and respiratory rate before/ after exercise
#11 How do people feel food?	*Experiment 12:* Examining the correctness of the taste map
#12 What changes in body temperature after eating food?	*Experiment 13:* Using a thermometer to explore whether people release energy before and after eating
#13 Why does the oxygen exhale decrease, and carbon dioxide increases after exercise?	*Experiment 14:* Using oxygen and carbon dioxide sensors to compare the exhaled proportions of oxygen and carbon dioxide before and after exercise

Notes: Problems #1 to #7 were identified in Phase 2, while Problems #8 to #13 were pursued in the first round of collective knowledge creation journey in Phase 3. All the experiments were conducted in Phase 3.

Theme 4. Comparing KB with scientists' work and designing the collective knowledge creation journey

To design the collective knowledge creation journey, students first reflected on how they conducted KB (Figure 4(a)) by asking questions and proposing theories (Theme 1), using the group-level IFM (Figure 2(b)) to conduct group communication (Theme 2), identifying critical problems and making conclusions/revising theories with the aid of the community-level IFM (Theme 3). Then they compared KB with how scientists work (Figure 4(b), from Grade Three's science textbook) to create a model of the knowledge creation process. At the stage, students integrated KB with how scientists work and transferred the two "procedures" into a circulating cycle (Figure 4(c)). Also, a "peer review" process and "community" was added in the journey to further promote the development of the entire community, as shown in Figure 4(d).

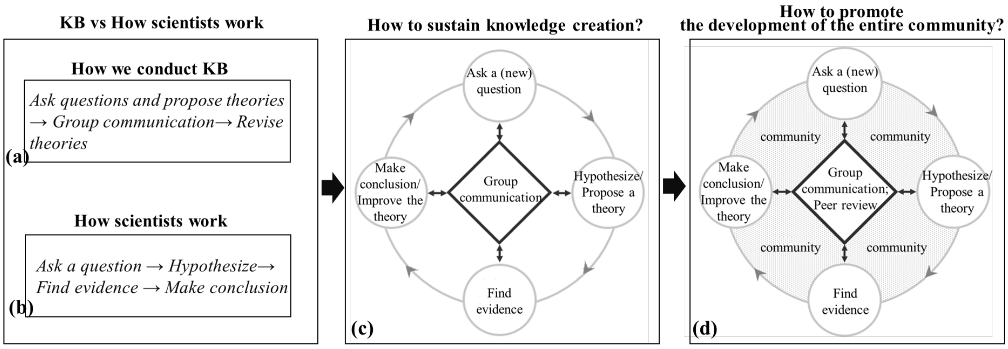

Figure 4. The design trajectory of the collective journey of knowledge creation.

Theme 5. Continuously creating new knowledge based on the collective journey of knowledge creation

During this phase, working in much more in-depth opportunistic groups, students carried out sustained inquiries of Problems #8 to #13 (Table 2). Take Group 1, who focused on Problem #8 (Table 2) in Phase 3, as an example. With the knowledge creation-level IFM (Figure 2(c)), the students in Group 1 found that the colored words "oxygen" and "carbon dioxide" were very close to the word of "breathe" and "exchange", which made them skeptical about the popular belief "The human body inhales oxygen and exhales carbon dioxide". They argued that "It takes only a few seconds for people to take one breath. Can all the oxygen be exchanged to carbon dioxide in such a short time?". Using the sensor technology (Figure 5 (a) and (b)), they found that the percentage of exhaled oxygen (16%) was much higher than carbon dioxide (4%) (Figure 5(c)), which is inconsistent with the popular belief. Later, Group 1 students generated an experimental report, which was published in *Popular Science,* a children's scientific journal affiliated to the science association. At the end of the paper, they wrote:

> "Many people believe that the human body exhales less oxygen than carbon dioxide. In fact, when we finished the experiment, we realized it was wrong.... The experiment is a magical process that turns the "universal truths" that people believe in "impossible" facts. In fact, the development of science is a process of constantly modifying the so-called "universal truths", as well as constantly approaching the facts."

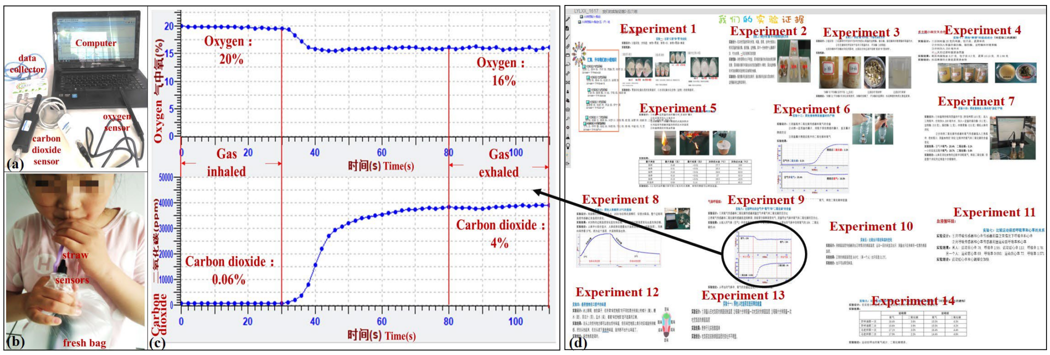

Figure 5. Materials (a), operation (b), results (c) and the *Research Evidence 2* view (d) of *Experiment 9.*

Based on the experiment result of Group 1, students in Group 5 & 9 continued to explore the knowledge creation-level IFM (Figure 2(c)), finding that the key ideas of "breathing" and "exchange" were very close to the idea of "blood". Then they carried out a sustained inquiry of Problem #10 in Table 2, proposed a hypothesis, collected evidence (*Experiment 11* in Table 2), and concluded that "Pulse and respiration rate will increase after exercise". Furthermore, through joint efforts, Group 1 & 4 & 5 & 9 identified that "exercise", "oxygen" and "carbon dioxide" were closely related in the knowledge creation-level IFM (Figure 2(c)). Thus, they further conducted a sustained inquiry of Problem #13, made a hypothesis, collected evidence (*Experiment 14* in Table 2), then provided an explanation from the perspective of energy consumption (Table 1, Group 4's pivotal note #415 in Week 9). Moreover, under the knowledge creation-level IFM, students put forward further inquiries, such as "Why are the calories of fried & non-fried potato chips so different?", "Where does the food turn into energy?", "Can meat provide more energy than vegetables?", "Why does the human body temperature slightly differ?", and "Why body temperature increases when having a fever?". These inquiries exhibited how IFMs with keywords scaffolded students in collective knowledge creation.

Discussion

This study contributes to the KB literature by investigating how Grade Five students pursed knowledge creation supported by IFMs and documenting students' collective knowledge creation journey in large communities. This study illuminates the mechanism and trajectories of elementary-school children working together to promote progressive knowledge creation; we also developed a new use of KF analysis (KBDex) to both analyze and to scaffold collective knowledge advancement. Results show the group-level IFM scaffolded high and medium-contribution groups to advance collective knowledge through bridging knowledge; the community-level IFM facilitated student groups' sustained inquiry; and the knowledge creation-level IFM provided supports through synthesis, lending support, sustained inquiry, and further theory building. Unlike most KB studies focusing on small classes, we conducted KB practice in large classes, based on the innovative design of social configuration (opportunistic group) and student inquiry into IFMs. The future study will further examine the improvements of IFMs and pedagogical designs, as well as how students develop progressive discourse in knowledge creation.

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