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Knowledge-building activity structures in Japanese elementary science pedagogy

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Abstract The purpose of this study is to refine Japanese elementary science activity structures by using a CSCL approach to transform the classroom into a knowledge-building community. We report design studies on two science lessons in two consecutive years and describe the progressive refinement of the activity structures. Through comparisons of student activities on- and off-line, it was found that the implementation of a CSCL environment facilitated students' idea-centered activity. The task requirement for students to engage in collective and reciprocal activities reflecting on their own ideas was also effective if it required students to use their conceptual understanding for producing something concrete.

Keywords CSCL · Japanese elementary science · Knowledge building · Design studies

Introduction

The purposes of our study are: (1) to improve Japanese elementary science curriculum using knowledge-building practices, and (2) to contribute to the advancement of development principles for designing knowledge-building communities in classrooms. First, we describe common Japanese elementary science activities and how they differ from knowledge-building practices (Scardamalia, 2002). Second, we discuss our redesign of Japanese elementary science lessons as knowledge-building practices by modifying and coordinating elementary science activities with a Computer-Supported Collaborative Learning (CSCL) technology called Knowledge Forum®. Finally, we report two design studies of modified elementary science lessons.

Japanese elementary science activity structures: an established culture of learning

Lessons in Japanese schools have activity structures that are established through repeated research lessons (Rohlen & LeTendre, 1995). Such repeated research lessons are particularly widely used by science teachers. Linn, Lewis, Tsuchida, and Songer (2000) videotaped and analyzed ten science lessons in five elementary schools in the Tokyo region. From their analysis, they found eight typical activity structures. They are as follows:

Connect lesson to student interest and prior knowledge. The teacher starts her lesson by asking what students know about the central concept they are to learn or with activities designed to make students really consider that the content to be learned is important. Instructional goals for this type of activity structure are to: (1) catalyze students' interest in the study topic, (2) help them think of their daily-life examples of the studied topic, and (3) bring out their prior knowledge or misconceptions about the learned scientific phenomenon.

Elicit student ideas or opinions. The teacher asks her students to express what they think of the scientific phenomenon or principle they are studying to: (1) help students review what they have learned so far, and (2) clarify or express their thoughts through writing or drawing.

Plan investigations. Students, supported by their teacher, consider hypotheses or predictions about the study topic and discuss methods for investigation. Teachers attempt to: (1) help students define a problem to investigate by discussing it in a systematic manner, (2) help them identify factors affecting the phenomenon they are focused on, and (3) evaluate students' comprehension and their insight into the scientific phenomenon.

Conduct investigation. Students conduct experiments or observations to test their hypotheses or predictions. In this activity structure, students are expected to learn to think about procedures to test their hypotheses or predictions, to experience designing and conducting scientific experiments, and to acquire specific skills to conduct experiments safely and successfully.

Exchange information from investigations. Students share their findings within their small groups or report them to the whole class. In this activity structure, students learn about others' ideas and thoughts, and relate or contrast their own ideas to them.

Systematically analyze or organize information. Teachers systematically summarize or organize the information or ideas that are shared by students to help them see patterns, similarities, or differences in their thoughts or findings so that students can use them effectively to draw conclusions.

Reflect and revisit hypotheses or predictions. Teachers encourage students to reflect on their current ideas and experimental findings to see if their earlier hypotheses or predictions are correct. They may encourage students to repeat the experiment if necessary. This activity structure is designed to help students gain insights into their own thoughts and problem solving, draw possible conclusions from the findings of their experiments, and connect these to their previous hypotheses.

Connect to next lessons. Identify unanswered questions. Teachers ask students to think about or write down what they want to investigate in the next lessons. By doing so, teachers have students connect the present lesson to the next lessons in a coherent way, sustain their interest in the study topic, and carry over their involvement as problem-solvers from the current lesson to the future.

Depending on their students' characteristics and classroom circumstances, science teachers in Japanese classrooms plan their lessons by using these activity structures. Each activity structure could function to facilitate the creation of a community of learners (Brown & Campione, 1996). When we as "deep constructivists" (Scardamalia & Bereiter, 2002) sit in the classroom, however, we rarely see students engage in that kind of knowledge advancement. We consider two reasons that these activity structures do not facilitate the desired sort of knowledge building in Japanese classrooms.

The first reason is that the activity structures identified by Linn et al. (2000) are not necessarily coordinated with each other to consolidate the classroom as a community of learners. The use of any activity structure independent of the others, or without any theoretical teaching or learning direction, does not lead the classroom to become a community of learners. As Brown and Campione (1996) point out, many failures in structuring the classroom as a community of learners stem from the fact that instructional designers do not have a systematic view on how to create a community of learners in classrooms.

The second reason that these activity structures are not creating knowledge-building communities in Japanese classrooms is that not all communities of learners are necessarily knowledge-building communities (Scardamalia, 2002; Scardamalia & Bereiter, 2002). Classroom environments for the two kinds of communities are designed to facilitate different types of learning. In a community of learners, the learners have responsibility for their learning activities. However, their control or intentionality is usually constrained in a context where a teacher takes over most of the responsibility for designing learning materials, curricula, the structure of group work, and goals to accomplish. In such a context of learning, learners are likely to have defined learning goals that they work hard to learn. Japanese elementary science lessons fit this type of classroom environment. In the knowledge-building community, on the contrary, participants need to have more responsibility for their own activities and the design of their learning conditions in order to advance their understanding by themselves. They need to regularly engage in objectifying knowledge to be improvable and shared, and they need to use that knowledge to create new knowledge. Participants in a knowledge-building community are, therefore, required to learn strategies not only to understand given knowledge, but also to advance knowledge by themselves.

Toward the knowledge-building classroom

Based on studies performed over more than ten years, Scardamalia (2002) describes 12 determinants of knowledge building (see Table 1). By referring to these 12 determinants of knowledge-building, we created two practical design principles.

The first principle was that continuously improvable student ideas are centered in the learning practice. Determinants such as “real ideas,” “authentic problems,” and “improvable ideas” were the most crucial issues that we found when designing lessons; our first principle is related to this realization. In Japanese lesson structures, student ideas are elicited several times during a lesson mainly for teachers to direct student learning toward predicted outcomes. Students are told by teachers to raise their ideas at some point, but this activity structure is not primarily designed for students to revisit their ideas for knowledge-building purposes. We applied our first principle to the design of our lesson plan by considering what forms of intermediate representations of student ideas should be created to share and improve those ideas.

Our second principle was that students should manage their ideas from diverse points of view and collaboratively advance their collective knowledge. This principle is related to determinants such as “idea diversity,” “community knowledge,” “collective responsibility,” and “symmetric knowledge advancement.” In ordinary Japanese classrooms, the idea of diversity is a quite familiar issue. Students raise many ideas and opinions from their individual points of view. However, their diverse ideas are not transformed into super-ordinate ideas through collective and symmetric activities. The socialization process is not systematically structured with emphases on

Table 1 Twelve determinants of knowledge building (Scardamalia, 2002)

Real ideas and authentic problems	Democratizing knowledge
Improvable ideas	Symmetric knowledge advancement
Idea diversity	Pervasive knowledge building
Rise above	Constructive uses of authoritative sources
Epistemic agency	Knowledge building discourse
Community knowledge, collective responsibility	Concurrent, embedded and transformative assessment

collective responsibility and symmetry of contributions. To improve student collaboration in the classroom, we applied our second principle to designing the participatory structure of student activities. Japanese activity structures are normally comprised of whole-class discussion and small-group work. We considered an intermediate level of the participatory structure: inter-group work. Inter-group work is an activity structure where students from different small groups share their ideas and comment on them in a way that bridges the whole classroom talk and the small group work.

Knowledge Forum® as a knowledge medium for facilitating the knowledge-building practice

The software introduced in our designed classroom was a Web version of Knowledge Forum®, called Web Knowledge Forum®. Although its functions for supporting student learning are somewhat simplified in comparison with the original client–server version, Web Knowledge Forum® is still a powerful medium for enabling learners to collaboratively reflect on previous ideas and to advance their collective knowledge through discourse. There are three reasons that Web Knowledge Forum® is a powerful medium.

First, learners report their ideas and thoughts in notes; each note is represented as a formatted report, as shown in Fig. 1 in the next section. When creating a new note or editing a previous note, learners can also add pictures or movies in HTML format from their private or public directories. Furthermore, they can add links by inputting note numbers. In the note, learners see basic information such as the author(s), production date, title, view (a specific sub-space of the conference room), and a hyperlink to the note that the original refers to (if applicable). Building on these main texts, Web Knowledge Forum® adds two types of linking information on the note that are mirror images of each other: (1) *references*, and (2) *notes that refer to the original note*. The *references* are a hyperlinked list of notes referred to by the original note. The *notes that refer to the original note* are a hyperlinked list of notes that refer to the original note. One list spreads outward from the original note, and the other list spreads inward to the original note. Thus, when reading a note, learners can jump back and forth and into and out of linked notes within the hyperlink structure.

Second, notes are reported in the space called "view." The "view" is a space designed by instructors or learners to report ideas related to a big idea or study topic, or a topic that is being discussed in one or more specific groups. The structure of views are dynamically created and refined as learning progresses. Notes reported in a view are then listed in the overall threaded structure as the default format. There are two additional formats for note lists: learners can sort notes in a view by author or date. These different structures are designed to help learners monitor their collective effort to advance their joint knowledge.

The third reason that Web Knowledge Forum® is a powerful medium is that the administrator can easily order or arrange views, linking one with another or restructuring them. She can also create a view map on the learner's initial log-in page. A visual representation of the view structure (e.g., views of different hypotheses of the same problem) supports learners in reflecting on previous activities, as well as in summarizing collective knowledge across views.

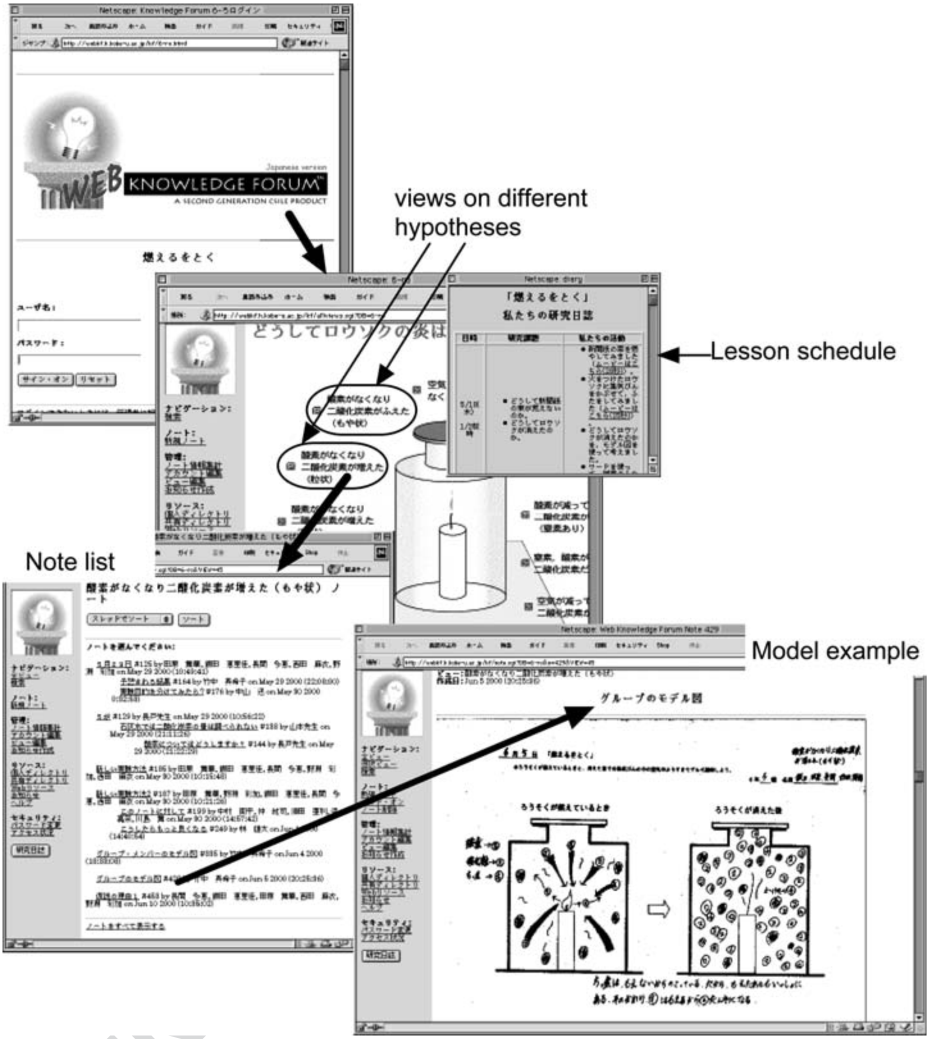

Fig. 1 The interface of Web Knowledge Forum® for ‘air and how things burn’

Design studies in Japanese elementary science

Participating classrooms

Since 2000, we have been collaborating with an elementary school affiliated with a public university. The teachers are all experienced and were selected to be in the school by various district education boards. The school’s mission is to function as a laboratory school in collaboration with the faculty of the affiliated university. Our design study project is one of several mission-based projects conducted at the school. Science teachers in the school have been involved in our design studies, and we have developed several lesson plans (two lessons a year) through discussion before, during, and after the classroom practices (Oshima et al., 2003).

The classrooms reported on in this study were a sixth-grade class for design study 1 on “Air and how things burn,” and a fifth-grade class for design study 2 on “How matter dissolves.” There were 41 students in the sixth-grade classroom and 34 students in the fifth-grade classroom. The lesson on “Air and how things burn” continued for 42 class hours (one class hour is 45 min long) in about two months, and the lesson on “How matter dissolves” lasted for 30 class hours in four months due to the inclusion of the winter break. The same teacher, who has more than ten years of teaching experience, was in charge of both classes.

We selected the two lessons for the following reasons. First, because the same teacher taught both lessons across two consecutive years, we determined that this would allow us to discuss progress in our design studies from one year to another. Second, the school wanted the teacher to conduct different study topics. Even though there were differences in the content domains, we concluded that we could discuss design principles for integrating Japanese elementary science activity structures and knowledge-building practices through the comparison of the two studies because the two lessons were designed with similar elementary science activity structures that emphasized different knowledge-building determinants.

Design study 1: “air and how things burn”

Elicit student ideas or opinion

We considered an initial question to elicit student ideas, particularly their explanations for a familiar phenomenon that they misunderstood. The question we asked students was whether a dense block of newspaper would burn and why they thought so. We asked this question after the students witnessed a crumpled newspaper ball burn easily. After the teacher demonstrated that the dense block of newspaper does not burn (or burn very well), the students were asked what is needed for things to burn. This revealed the students’ initial ideas on combustion. The teacher performed an experiment illustrating how a candle stops burning when placed in a closed jar. This required students to consider the phenomenon more scientifically, based on their initial ideas (Oshima et al., 2002). The learning goal for the students in this lesson was collaborative theory construction through experimentation on the burning phenomenon.

Plan investigations

Based on similarities of individual student explanations reported in the form of models (drawings) on Knowledge Forum®, students were grouped into small research teams, each of which pursued their own inquiry into the target phenomenon.1[1] Each research team had their own view on Knowledge Forum® where they reported their ideas and comments (see Fig. 1). To test hypotheses derived from their own initial theories, they first planned experimental designs and reported them in notes in their views. Through discussion on- or off-line with others, including the main teacher, other science teachers (on-line), and researchers (the

[1] In design study 1, students used computers to access the database in the computer room, which was different from the science room where they usually had classes. Although students mainly worked in teams, they could use computers individually.

authors), students refined their experimental designs before actually conducting their experiments.

Conduct investigation

Each team conducted their experiment by themselves under the supervision of the main teacher. Before their experiments, students were instructed to consider what to observe and record for sharing information with other teams.

Reflect and revisit hypotheses or predictions

After their experiments, students reported whether their predictions or hypotheses were shown to be correct, and how they wanted to revise them based on the outcome of the experiment.

Exchange information from investigations

Students shared their experiment reports with other teams on Knowledge Forum® and discussed with the whole classroom how they further advanced their learning.

Systematically analyze or organize information

While reading the notes of other teams on Knowledge Forum® and discussing them with the class, students had the opportunity to compare varying explanations of the phenomenon under study, and to consider more articulate and convincing theories.

Connect to next lessons

After the classroom talk, students were told to regroup with their own team to revise their ideas based on their findings and discussion.

During the lesson, the sequence above was repeated three times, or until students finally figured out a convincing theory, i.e., "a candle stops burning if the proportion of oxygen in the air is decreased below a specific percentage." In the second and the third sequences, some phases such as planning and conducting investigations were taken over by the teacher, who did demonstration experiments. The main activities of the students were to reflect on the experiments, exchange their ideas, and systematically analyze their thoughts on Knowledge Forum® and in classroom talk.

Our contributions to the design of the lesson, based on our two design principles, were: (1) to use students' explanatory models and experimental reports as conceptual artifacts centered in their science activities, and (2) to get students to engage in collaborative work on their artifacts in order to advance their collective knowledge. Thus, we designed the lesson as sequences of scientific inquiry by small research teams that frequently shared their thoughts and findings on and off line.

Design study 1: evaluations

To evaluate whether we advanced the lesson toward better knowledge-building practices, we analyzed access logs on Knowledge Forum® and observed student activities on and off line. Although the access logs provided us with limited information about on-line student activities, they did give us an opportunity to gain insight on how student activities in the lesson were idea-centered. As described, we designed the lesson in which students reported their explanatory models and experimental reports on Knowledge Forum® in different activity structures. Based on the logs, we analyzed what proportion of idea-centered notes—i.e., their explanatory models and discussion of the models—were accessed by other students. Notes created by students were first categorized into *idea-* and *fact-based*. When students drew models or discussed their own or others' models in notes, the notes were categorized as *idea-based*. Other notes in which students reported the results of their experiments or experimental procedures were categorized as *fact-based*. The proportion of notes read by each research team, excluding their own notes, was calculated. A t-test on the proportions of idea- and fact-based notes showed that students read significantly more fact-based notes (the mean was 20.10% with 9.05 as SD) than idea-based notes (the mean was 5.70% with 1.78 as SD; $t(10) = 5.54$, $p < 0.01$).

Based on the observation data on and off line, student activities in the lesson were summarized as follows. Student ideas were continuously revisited and improved when revising their models. For the first experiment, explanatory models by some teams referred to components of the air, but others did not. Shared information across research teams after the experiment led students to consider the three main components of air. Teacher-directed demonstration experiments on characteristics of different components of the air, i.e., oxygen, nitrogen, and carbon dioxide, during the second sequence of experiments facilitated students in thinking about the target phenomenon, "a candle stops burning in a closed jar," while paying attention to the components of the air.

However, students focused their attention on constructing their theories within their teams but did not consider their contribution to collective knowledge in the classroom. Explanatory models based on the three different components of the air were disseminated through their reading each others' notes. The new idea about components of the air did not lead students to construct inter-group theories. One research team did raise a question about the need of oxygen for a candle to continue burning, "In our experiment, there was some portion of oxygen after a candle stopped burning. We wonder why the oxygen did not help the candle keep burning." Unfortunately, this idea did not get the attention of the other teams. Finally, students constructed their theory of how things burn in the air, "A certain amount of oxygen is needed for things to burn. As things burn, oxygen around the things is gradually consumed and decreases below the amount necessary for things to continue burning." Thus, they used only oxygen to explain why a candle stops burning in a closed jar even though they had paid attention to the idea that the air is comprised of three different components. The crucial phenomenon that carbon dioxide surrounds the flame so that oxygen cannot reach it was ignored.

We concluded from our analysis and observation that our design effort did not satisfy the "community knowledge," "collective responsibility," and "symmetric knowledge advancement" determinants of knowledge building even though the class could invent models and experimental reports and use them as shared conceptual artifacts. In design study 2, therefore, we further altered activity structures in the lesson based on our evaluation of design study 1.

Design study 2: "how matter dissolves"

In design study 2, we designed another lesson: "how matter dissolves." We again applied elementary science activity structures to designing the lesson. However, we revised the task and participatory structure. In design study 1, we set a target phenomenon for students to continuously engage with through the improvement of their explanatory models. Students engaged in their *real ideas* in the lesson, but the task itself was *not authentic* enough for them to compare or synthesize their ideas between small research teams. Different research teams conducted their investigations for different purposes. Although experimental reports were sharable in the classroom, it was difficult for the students to *rise above* diverse ideas from different teams. We did not prepare supports or scaffolding for students to take on such a difficult task.

The participatory structure in design study 1 was not organized to support students' engagement in *collective knowledge advancement*. Collective activity for students to socialize their knowledge in a more global community, e.g., from ideas within a research team to those among teams, and from ideas among teams to those in the classroom as a whole, was implemented in a quite limited part of the total learning process. Activities were mainly conducted under the teacher's supervision in classroom talk after students were given opportunities to read and comment on the reports of others in Knowledge Forum®. As the log analysis showed, students were concerned with facts or findings by other teams rather than the ideas of others teams. The proportion of the notes accessed by students from different teams was not high enough to conclude that they were engaged in collective knowledge advancement.

In design study 2, the lesson started with the teacher's question on how students define dissolution. Students had naive ideas of dissolution, such as "If you cannot see the matter in the water, it is dissolved." Then, the teacher demonstrated an experiment on the difference between dissolution and admixture. He put an equal amount of aluminum and cornstarch in different cups of water and mixed them until they could not be seen. After 10 min or so, students were asked whether the two solutions were dissolved or not. The students were focused on the differences in appearance between the two solutions. Through the comparison in conditions between the solutions, students achieved a more accurate idea about dissolution. Further, the teacher demonstrated several experiments for identifying characteristics of the dissolving phenomenon: (1) dissolved matter exists in the water even if it is not seen, (2) matter is distributed equally throughout the water, (3) the full mass of the dissolved matters exists in the water, (4) the higher the temperature of the water, the greater the amount of matter that can be dissolved, (5) the greater the amount of the water, the greater the amount of matter that can be dissolved, and (6) matter is deposited if the water temperature of a solution is decreased. Finally, students worked on simulation software to see what happens in the water at the molecular level. With the simulation software, students manipulated the water temperature and the amount of aluminum added to see what happens to the water and aluminum molecules when they dissolve and deposit. Students discussed their explanations of dissolution at the molecule level on Knowledge Forum® and in classroom talk, and then identified various characteristics of dissolving and depositing.

Elicit student ideas and opinions

The teacher proposed to students that they should further investigate the best conditions for creating a big and beautiful aluminum crystal based on their collective knowledge of dissolving and depositing. In the classroom talk, students discussed the definitions of size and beauty before they conducted their investigations. They concluded that the size of the crystals they created would be measured by mass, and that beauty would be measured by the crystal's transparency and regular octahedron shape. The task structure applied in design study 2 was crucially different from that in design study 1. Both task structures were similar in that students were required to consider scientific mechanisms and explain their models. However, in design study 2, we asked students to use their conceptual understanding to solve an authentic task—creating a big and beautiful aluminum crystal—and improve their conceptual models through investigation. Since they shared an articulated task goal, the different research teams were expected to engage in more collective and symmetric knowledge advancement.

Plan investigations

In Knowledge Forum®[2] students in the research teams reported their ideas and experimental designs for investigating their ideas about how to make a big and beautiful aluminum crystal. They mainly considered the water temperature and the amount of aluminum that should be dissolved.

Conduct investigation

Students conducted their experiments with their experimental design sheets. They first heated a beaker with a certain amount of water at the temperature they specified, and then dissolved the specified amount of aluminum. Finally, they left the beaker for a week until the aluminum was deposited.

Reflect and revisit hypotheses or predictions

A week later, students checked the results, reported on what their crystals looked like with pictures, interpreted the results, and discussed on line how they could refine their experimental designs to create bigger and more beautiful crystals.

Exchange information from investigations

In design study 2, we revised the activity structure as follows. First, before students shared information among different research teams on Knowledge Forum®, the teacher encouraged students to briefly report their progress in the classroom talk.

[2] In design study 2, students used computers in the science room where they had their science classes. A desktop computer was prepared for each research team. Students in a team collaboratively accessed and commented on the reports of others.

Then, students went back to their research teams to read and comment on the reports of others, and to discuss how they could build new ideas from the reports.

Systematically analyze or organize information

Following the *exchange information from investigations* activity, students discussed with the class what they knew and defined a general direction for further research.

Connect to next lessons

Finally, each research team discussed the next experimental design based on shared information and reported on the design by revising their notes.

The second and third sequences of activity were basically the same as the first sequence. However, students' scientific practices were more elaborate because of their discussion of results in the third sequence. They were more elaborate in three ways.

First, through the *systematically analyze or organize information* activity, they identified several factors that they believed affected the size and beauty of the crystals they created: (1) the amount of water, (2) the position of the end of the string where crystals are generated, (3) the existence of a seed crystal at the end of the string, (4) the cooling speed of water, (5) the amount of aluminum dissolved in the water, and (6) the temperature at which they start to put aluminum in the water. Second, as a result of the classroom talk, the students determined that they needed a control condition in each research team to rigorously test their predictions. They collaboratively designed experiments by distributing different factors for the teams to investigate. Third, some factors, such as the amount of water, were compared between conditions in different teams' experiments. For instance, two research teams pursued the question of whether the position of the edge of string affects the size and the beauty of generated crystals with different amount of water, 200 and 300 cc. Fourth, students attempted to predict the results of their experimental conditions and explained why they made the predictions they did by drawing models of the depositing phenomenon. Thus, in the final sequence of activity structures, students engaged more collaboratively in scientific inquiry and produced more scientific experimental reports and explanations.

Design study 2: evaluation

Design study 2 was conducted to evaluate whether changes in task and participatory structures improve student learning and knowledge building, particularly idea-centered activity and collective knowledge advancement. Based on students' access logs, the proportions of idea- and fact-based notes accessed by students were compared. A 2 (Design Study) $\times$ 2 (Note Type) ANOVA on proportions of accessed notes showed that: (1) proportions of accessed notes in design study 2 were significantly higher than those in design study 1 ($F(1, 18) = 16.11$, $p < 0.01$), and (2) proportions of accessed *fact-based* notes were significantly higher than those of accessed *idea-based* notes ($F(1, 18) = 19.89$, $p < 0.01$) (Fig. 2). The results can be interpreted as follows. First, student activities in design study 2 were more based on collective and symmetric knowledge advancement. Hence, the students accessed the

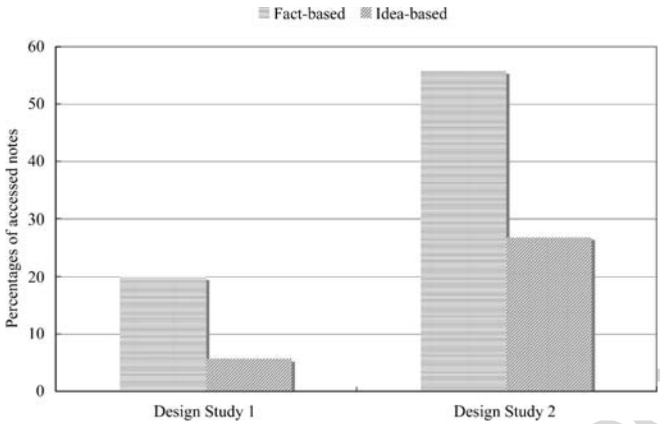

Fig. 2 Proportions of notes accessed by students across two design studies

reports of others to a greater degree (either *fact-based* or *idea-based*). Second, student activities in design study 2 were more idea-based than those in design study 1. Thus, the statistical measures suggest that our refinement of activity structures in the lesson improved students' learning activity to be closer to knowledge building.

Our conclusion, based on the statistical analysis here, still has some reasonable doubts. Although students in design study 2 accessed a greater proportion of notes than did those in design study 1, it might be the result of those in design study 1 having to access significantly more notes in the context of their learning. To clarify that possibility, we analyzed the actual numbers of accessed notes in both design studies. A 2 (Design Study) × 2 (Note Type) ANOVA on note numbers showed: (1) that students in design study 2 accessed significantly more notes ($F(1, 18) = 14.50$, $p < 0.01$), and (2) that there was found to be a significant difference in the note numbers of *fact-based* notes ($F(1, 18) = 38.84$, $p < 0.01$). What we found based on the analysis of actual numbers of notes are: (1) that students' activities in design study 2 were more collective and symmetric, but (2) that the activities of those in design study 1 were just as idea-centered.

Nonetheless, taking the results of analyses on two different measures and the characteristics of lesson practices into consideration, we infer that student activities in design study 2 were more idea-centered. This is because the features of the design study (particularly time arrangement) were dynamically revised from monitoring student activities after design study 1. When we found that students had to access many notes in order to share their ideas with the class, we decided to extend that phase before going on to the next phase. Students in design study 1, therefore, had more time to access idea-centered notes. Non-significant differences in the actual numbers of accessed *idea-centered* notes suggests that students in design study 1 were not likely to take the time to access more idea-centered notes. We further discuss whether students in design study 2 were more idea-centered based on case-based analysis.

Further observatory data on and off line support our conclusion that the lesson in design study 2 was improved from that in design study 1. Here, we describe how a research team we observed in depth was engaged in knowledge building in the three sequences of investigation.

In the lesson on "how matter dissolves," students were divided into nine research teams to create crystals. One of the teams (called team A) was found to profoundly engage in knowledge building practices on and off line. In the first sequence of their investigation on how to create a big and beautiful aluminum crystal, they designed an experiment and completely failed to create a crystal. In the first experiment, the team set the condition by specifying the amount of water in a beaker (200 cc), the temperature at which to start adding aluminum (40°C), the mass of aluminum to add (100 g) and the use of a string without a seed crystal.

In the *exchange information from investigations* activity, team A read experimental reports from all other teams and systematically analyzed and organized the experimental results from the classroom. Through their systematic analysis of the results of the first experiments in the class, they reported a note called "discussion on results."

> We compared experimental designs between successful and failed experiments. What we found from the comparison is that we should further heat the water up to 80 degrees Celsius so that we can completely dissolve aluminum in the water, and the edge of the string should not be close to the bottom of the beaker otherwise aluminum particles are deposited on the bottom. (Note #109)

In the second sequence of their investigation, team A revised their experimental design by specifying: (1) the amount of water (200 cc), the temperature to start adding aluminum (80°C), the mass of aluminum to dissolve (125 g), and the position of the edge of string (three quarters of the way into the beaker). A week later, they found that they had succeeded in creating aluminum crystals in their beaker. Again, the team systematically analyzed results of the second experiment by the other teams to further elaborate their final experimental design. Other teams also analyzed the results of the class in the first sequence, and their ideas were shared in classroom talk. This activity structure facilitated students in improving their experimental designs in the second sequence, as we saw in team A. When team A accessed the experimental reports of other teams in the second investigation, the experimental conditions team A found were more various and elaborated than those in the first investigation.

In the second experimental designs, two new factors appeared: (1) use of a seed crystal, and (2) the way of cooling water in the beaker. Our observation of student activities in the classroom suggests that these two factors were applied to their second experiments through their reflection on the first experiments and through their use of the simulation software. After the first experiments, teams went back to the simulation software to see what happens in the water at the molecular level. Some students paid attention to the manner in which dissolved aluminum molecules were deposited. They reported in the classroom talk that the size and the beauty of a crystal might be affected by the manner in which aluminum molecules were composed again. This idea was converted into the two articulated factors: the cooling speed and use of a seed crystal. Some students made the inference that quick cooling would make a bigger crystal since many molecules were deposited quickly. On the other hand, there were students who made the inference that slow cooling would make a more beautiful crystal since there would be sufficient time for molecules to be deposited in a systematic way.

Team A categorized results into three different types (i.e., successful, partially successful, and failure) and compared their experimental conditions to elaborate their third experimental design. They revised the second experimental design by changing the mass of aluminum to add (as much as could be dissolved), and using a seed crystal and a temperature stabilizer to slowly cool water in the beaker. They prepared a control condition without a seed crystal for testing whether or not the seed crystal helps to develop a bigger and more beautiful crystal. Team A explained why they chose this condition by using a molecular level of representation. They explained that a seed crystal attracts other aluminum molecules, which help to develop a bigger crystal, whereas many molecules just fall down to the bottom when a seed crystal is not used. The team succeeded in creating a bigger and more beautiful crystal than those in their first and second experiment, and reported from the comparison of the two conditions that the use of a seed crystal helps to make a bigger crystal but did not affect the beauty.

The description of students' activities in team A suggests that the students constantly engaged in improving their ideas through their collaboration with other teams. Activities to systematically analyze and organize information from different investigations that were seen in team A were found in other teams as well. As the analysis of the access logs showed, our observation analysis of students' activities on and off line shows that the scientific inquiry of students in design study 2 was more symmetric and closer to knowledge-building practices than those in design study 1.

Discussion

We reported two design studies in which we refined Japanese elementary science activity structures for transforming the classroom into a knowledge building community. There have been several studies on knowledge-building approaches to science education in other countries (e.g., Hakkarainen & Sintonen, 2002; Lee, Chan, & van Aalst, 2006). Hakkarainen and Sintonen (2002) proposed a new approach to define student scientific inquiry based on the interrogative model (Hintikka, 1988). They succeeded in articulating the process of student inquiry on CSILE (the former version of Knowledge Froum®). Lee et al. (2006) investigated the effectiveness of knowledge-building scaffolding for assessing the progress of high school students' scientific inquiry. They found that the portfolio guided by knowledge-building principles (Scardamalia, 2002) was a powerful tool for high-school students to elevate their level of conceptual understanding of complex scientific concepts. The focus of our research here was on whether we can refine the current culturally established practice of scientific inquiry by elementary-school students by inventing general but powerful design elements (the task structure and the participatory structure) with a CSCL technology. In this section, we summarize the results of the studies, discuss whether we succeeded in the transformation of the classroom by refining two "design elements"—the task structure and the participatory structure in design study 2—and raise problems we identified from the studies (Collins, Joseph, & Bielaczyc, 2004).

In applying Japanese elementary science activity structures in our design studies, we developed two design principles for transforming the class structure into knowledge-building practice: (1) idea-centered lesson, and (2) collective knowledge advancement. Our observation analysis of student activities on and off line showed that students were involved in scientific inquiry with their ideas being centered in both lessons. They expressed, revisited, and revised their explanatory models through their investigations. Conceptual artifacts like models facilitated students' reflection on the relationship between their ideas (models and hypotheses) and experimental results, and new ideas and questions emerged. In the lesson on "Air and how things burn," such an idea emergence was seen when students paid attention to modeling how the three main components of air affect a burning candle in a closed jar. As we described in our observation analysis, a team raised an intriguing question: "we know that oxygen helps a candle burn. Why does a candle stop burning even if oxygen is still there?" Unfortunately, this emergent problem was not further pursued in their learning. We considered several reasons for students to have missed the important opportunity to deepen their conceptual understanding. One reason is that it was difficult for students to plan and conduct investigations on this issue. The teacher agreed with us that students would not have the repertoire of experimental designs in their minds even if they had been concerned with this problem. The most crucial reason, we believe, is that the worth of the concern was not collectively recognized by other students. As the analysis of the access logs shows, the proportion of *idea-based* notes read by students in this lesson was quite low. Such an asymmetric or non-collective activity structure kept students from rising above their ideas to form a new perspective.

In the lesson on "How matter dissolves," the problem students engaged in was to use their understanding of dissolving and depositing phenomenon to create a big and beautiful aluminum crystal and to figure out the mechanism of how such big and beautiful crystals are created. In such a task structure, explanatory models were conceptual artifacts used to solve the problem as well as knowledge objects to improve. Student ideas were centered in their activity all the time. From one sequence of the investigation to another, students gradually created a "frame of their hypothesis space" (Klahr, 2000), and improved the conceptual models behind their hypotheses. After the experiments, they carefully compared their results to their predictions, used the simulation software to consider what happened at the molecular level, and made inferences to improve their hypotheses. The anecdote that they found two new variables (a seed crystal and cooling speed) through their reflection on their use of the simulation software is a good example.

In design study 2, knowledge advancement was more collective and symmetric than that in design study 1. One reason for such collective and symmetric knowledge advancement is the refinement of *the task structure* in the lesson. Students were engaged in fun and authentic problem solving—the creation of a big and beautiful crystal—which required them to do scientific inquiry based on their knowledge and learning. In such an authentic problem-solving situation, the technology to share ideas facilitates student activities to collaboratively deepen their conceptual understanding. Another design element we can count on is *the participatory structure* we designed for sharing information from investigations by others. In design study 1, we implemented Knowledge Forum® as a means for students to engage in communication between teams, i.e., the communication layer between communication within teams and classroom talk. We found, however, that the implementation of such a new knowledge medium and preparation time for using it did not encourage students to engage in inter-group communication. The participatory structure we applied in design study 2 for improving the situation was to implement brief classroom talks for each team of students to report their progress before the students really searched for the notes of others. The blending of off- and on-line communication for student progress helped them understand what their class as a community knew and what problems or questions remained, or which groups had similar interests and important data. It facilitated more effective use of searching the database for new ideas.

Thus, the task and participatory structure we refined in the Japanese elementary science activity facilitated students' idea-centered, collective and symmetric knowledge advancement. It may be useful for us to return to the lesson in design study 1 for considering how we can improve the overall lesson practice based on our findings in design study 2. With regard to the participatory structure, we think that we can similarly apply the blending of off- and on-line communication depending on the task structure and student activity structure. We need to pay more attention to the task structure, however. Combustion itself is still a mysterious concept that requires further scientific endeavor. It is difficult for us to provide students with a task structure, based on which students themselves engage in authentic and collaborative problem solving, by explaining the scientific mechanism. Even so, we consider that we can critically improve students' activities and knowledge-building practices by providing the scientific model to engineer something visible in experiments. For instance, "Designing a fireplace in a house for effectively warming up without the risk of CO poisoning" or "Producing an effective fire extinguisher" would be a motivating task for students to use their conceptual artifacts. We need further collaboration with scientists and curriculum designers to develop a task structure effective for studying combustion in the elementary school.

Finally, we still have several issues we have to overcome. An issue we have to further consider is that students easily focus on task goals when they require them to *do* something concrete such as construct a product. We found in design study 2 that some students were task-goal directed and did not consider conceptual aspects of the activity. The coordination of doing scientific inquiry and building knowledge through such practices should be further discussed in order to find general knowledge-building activity structures.

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AUTHOR QUERIES

AUTHOR PLEASE ANSWER ALL QUERIES.

Q1. Please provide history dates.
Q2. Hintikka (1988) was cited in the main text but is not found in the reference list.
Q3. Bereiter (1994, 2002); Brown (1992); Cobb (2001); Collins (1999); van Dijk and Kinstch (1983) were uncited references.